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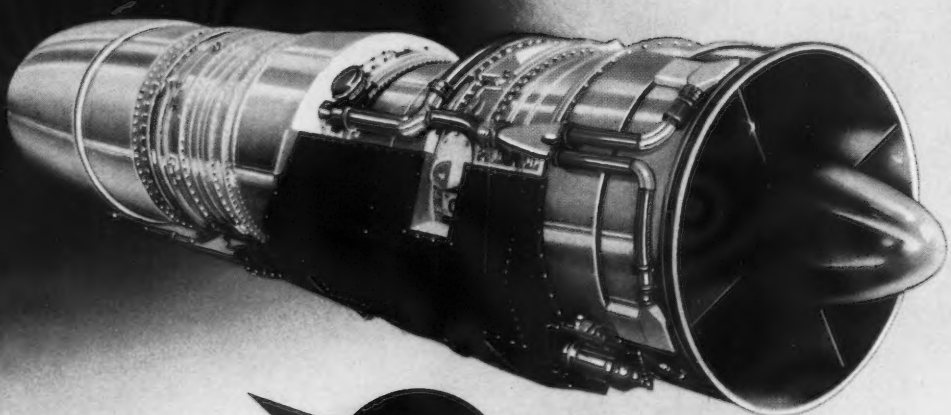
ORENDAS . . .

IN OPERATIONAL SERVICE ON FOUR CONTINENTS



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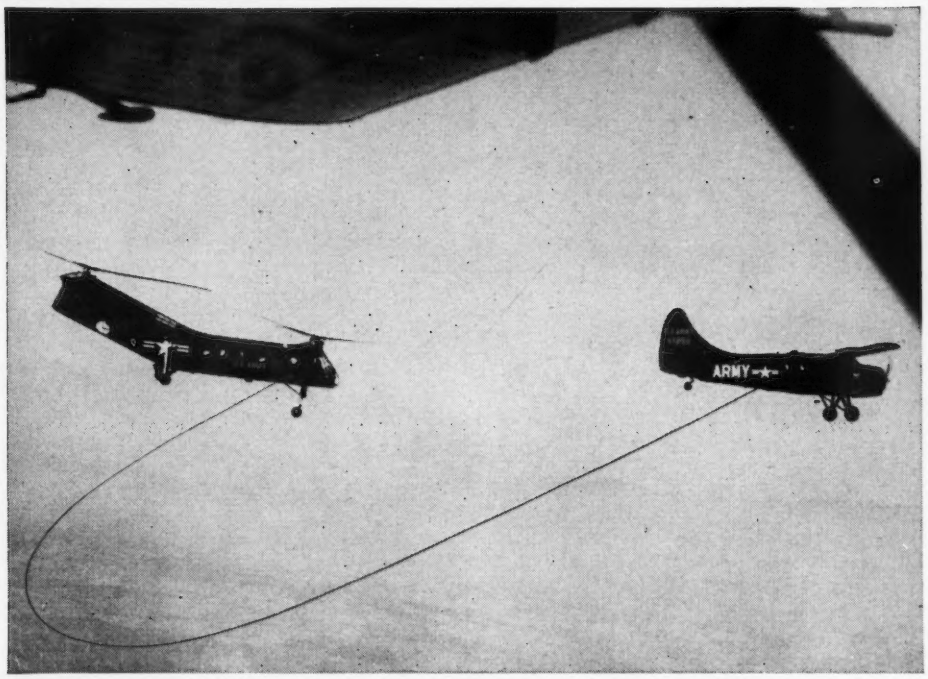

The maximum range of the Vertol H-21C light cargo helicopter is approximately 300 miles. Yet, on August 25th, 1956 an H-21C touched down at the Pentagon heliport, Washington, D.C. to complete a nearly 2700 mile non-stop flight from San Diego, California.

Army aviation officers were quick to say that the 32-hour flight proved the practicability of ferrying helicopters as much as 3000 miles to increase the striking power and mobility of ground forces.

A major assist was given to the Army's whirlybird on its transcontinental flight by a U.S. Army U-1A Otter aircraft. The Otter, converted into a flying fuel tank, refueled the H-21C in flight over Wink, Tex.; between Big Springs and Abilene, Tex.; at Maxwell AFB, Ala.; and at Fort Benning, Ga.

For the Canadian designed and built Otter, the job of wet nursing a cross-continental helicopter was just another routine chore. Many hundreds of Otters and Beavers function as prime utility support for the U.S. Army.

After refueling the helicopter, it was necessary for the Otter to land and take on fuel, and then, after dropping far behind, set out to overtake the helicopter on its non-stop trans-continental flight. Great credit is due to Captain Leonard F. Seitz, Captain James H. Stebbins, SFC Joseph Loncar and SP/3 Charles H. Glass, the crew of the U1-A tanker who carried on with little food and no rest for 30 hours continuously, as well as to the gallant crew of the H-21C.

The Otter was a logical choice to provide in-flight refueling of the H-21C. Its exceptional control qualities at slow flying speed and the high position of the tail plane combine to facilitate efficient co-ordination of the refueling maneuver. Additionally, the generous cabin space facilitates the cargoing of a maximum fuel payload.

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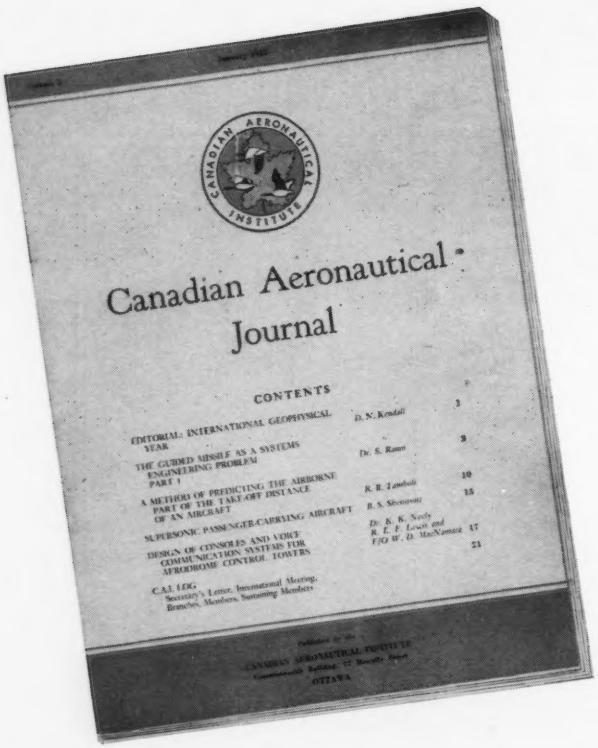

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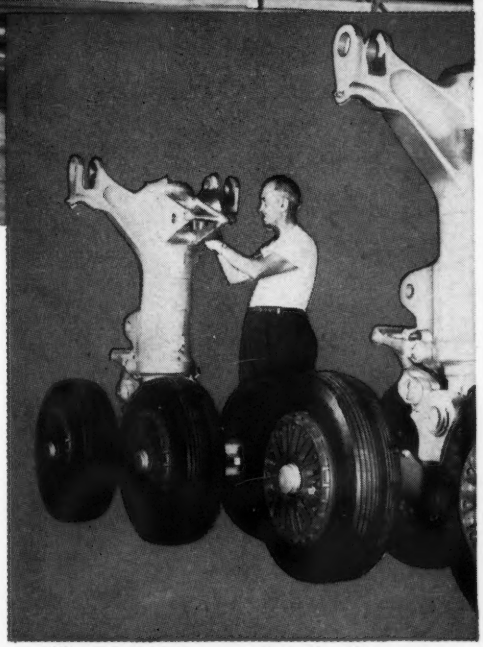

on the completion of the first CL-28

The production of the CL-28 marks another large step forward in the progress of Canada's aircraft industry. Canadair Ltd. is to be congratulated on their success in this giant undertaking.

Jarry Hydraulics is proud of its association with Canadair in their achievement. The main and nose landing gear were built by Jarry Hydraulics along with other components which were designed to meet the rigid demands of this huge aircraft.

The photo above graphically illustrates the size of the landing gear in the compressed position.

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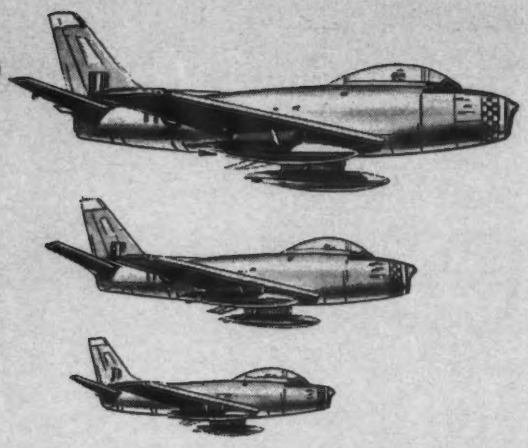

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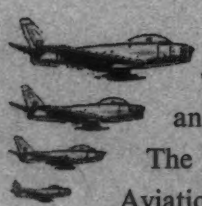

Selection of the Canadair Sabre VI by the Federal Republic of Germany is a reflection of confidence in the proven reputation and performance ability of Canadair and the products it makes. The Sabre VI, developed under license from North American Aviation Incorporated, is one of the world's great day superiority fighters and performs with unrestricted manoeuverability and speed within its design characteristics. Behind it stand the vast manufacturing and engineering resources of Canadair, supported by an established record of on-time deliveries for which the company is renowned.

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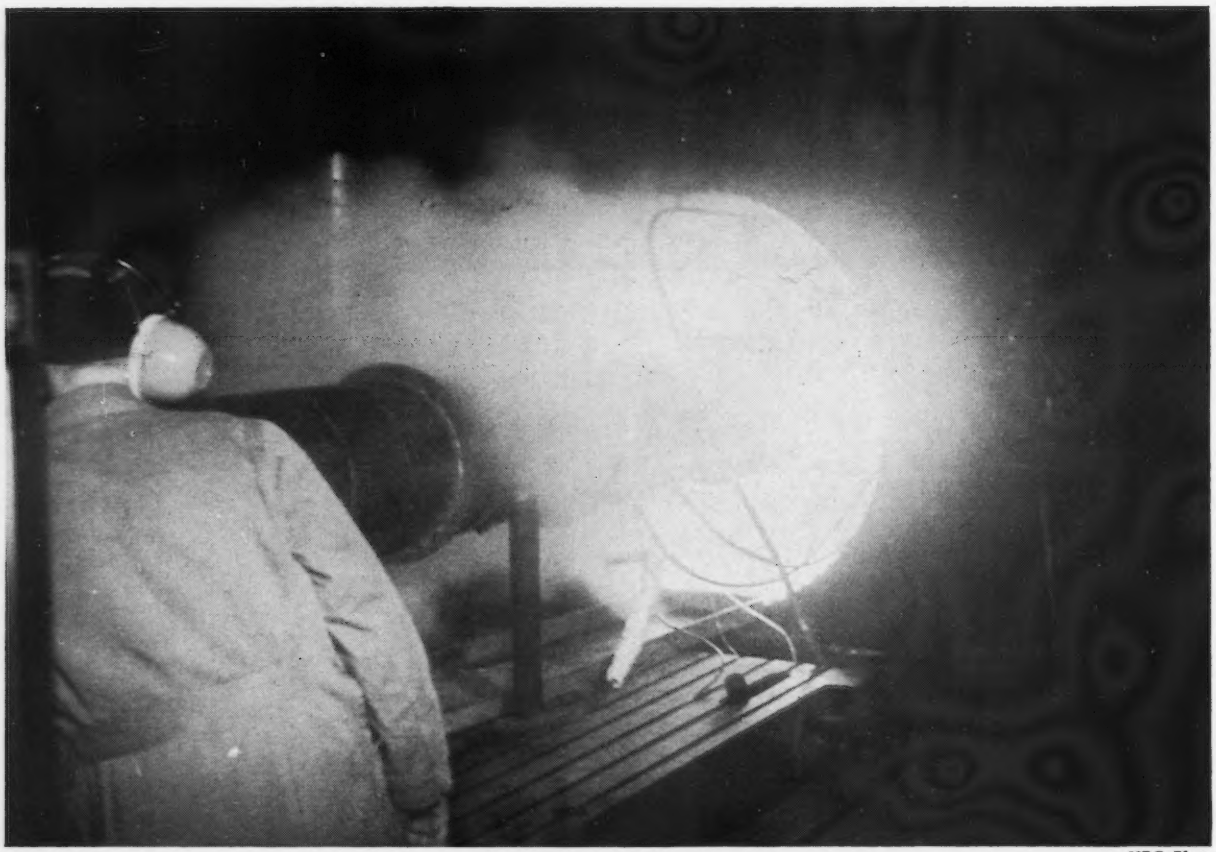
SCREECHING COMBUSTION



NRC Photo

National Research Council full-scale test rig for screeching combustion under severe screech conditions.
(See page 36)

EDITORIAL

TIME TO SPARE

In the Inaugural Address, delivered at the first meeting of the Institute on the 25th May, 1954, Air Vice Marshal Alan Ferrier reviewed the statistics of present-day air travel and pointed out that relatively few people regard flying as an accepted form of personal transportation. He said,

> "With the benefit of mankind as a whole in mind, I venture to urge that the objective is to put the advantages of aviation in reach of more people. If speed contributes to that cause, by all means let us have speed, but never let us forget the main objective."

Speed has generally been regarded as about the only thing that aviation has to offer. It has been the "advantage of aviation" most widely exploited by the airlines and the principle has been well established that the fastest airliner will get the business. Up to date, the principle has held; faster aeroplanes, though more costly to operate than their predecessors, have attracted the passengers and so, by flying consistently with a good payload, they have proved to be economical. Thus has progress been achieved, from speed to more speed. And now Mr. B. S. Shenstone, in his paper appearing in the last issue, is looking forward to supersonic air transports, but he stresses that such aircraft must be not only better but bigger, in order to carry enough passengers to make them pay.

People will always be in a hurry and people will always be attracted, for various reasons, to fast aeroplanes. No doubt the fast transport is here to stay and to get faster and faster.

However, speed is not the only "advantage of aviation", as our northern operations have demonstrated for years. The ability of aircraft to get at inaccessible places has been exploited militarily and commercially and its benefits will be realized to the full when VTOL techniques have been perfected. Though this quality may entail some limitation of speed, there is still an ample margin over the best that surface transport can provide.

Perhaps some of us should take our eyes off Dr. Mach for a moment and look back to more leisurely flight. It is interesting to consider the commercial possibilities of an aircraft built to the modest requirement that it should be faster than a train, as mechanically reliable and almost as independent of the weather. If we were to apply all our present knowledge — about safety, about control, about aerodynamic performance, about economy, about materials, about anti-icing and de-icing, about instrument flying, about noise suppression and about air-conditioning — if we were to apply all this and all the resources of modern science to the production of a reliable and comfortable means of getting from A to B, without undue emphasis on speed, we might achieve a remarkably cheap form of travel. And, if the answer is a small aeroplane, we might make it cheaper still by discarding the expensive machinery of reservations and adopting high frequency services instead.

It is not suggested that the high speed airliner should be abandoned — far from it; for trans-ocean and trans-continental express services, it obviously has no competitor. But if we are to put the advantages of aviation in reach of more people, we might well pay more attention to the air coach.

SCREECHING COMBUSTION

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Figure 1

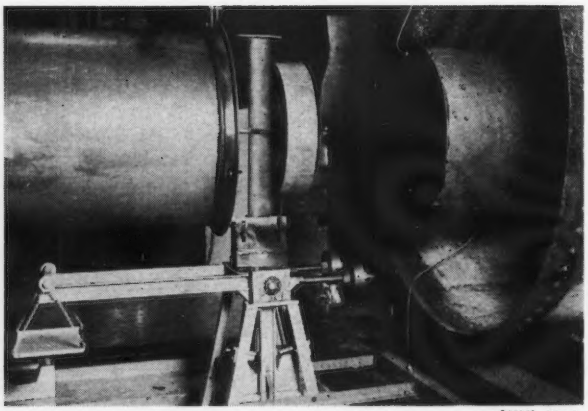

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Figure 2

In the development work on reheat systems of turbo-jet engines a phenomenon called "screech" is often encountered. The name of this phenomenon has been derived from its audible manifestation, a shrill screeching noise which is produced by the combustion.

Screech often has a destructive effect on the engine tail pipe or afterburner, such as loosened bolts, cracked welded seams, broken igniters, broken or burnt flame-holders, failures of the tail pipe wall etc. Since the proneness to screech increases with the reheat fuel flow, screeching combustion represents a serious limitation factor of the thrust boost by reheat.

In view of the importance of the screech danger, some time ago the National Research Council started an investigation, the first objective of which was to discover the nature of this phenomenon. Experiments were conducted on small and full scale rigs and on engines. They showed that the screeching is caused by high-frequency (many hundred cycles per second, depending on tail pipe diameter) gas oscillations of tangential or transverse type with the gas moving from wall to wall, thus, so to say, "sloshing" across the tail pipe. The measurement of pressure variation in the tail pipe, close to the reheat flame stabilizer, showed the maximum peak-to-peak amplitude of 20 psi during severe screech. The frequencies of mechanical vibrations of the tail pipe were found to be in agreement with the acoustical and pressure oscillation frequencies of screech. The destructiveness of screeching combustion is ascribed to these mechanical vibrations, as well as to the increased rate of heat transfer.

The noise level during violent screech exceeds 140 decibels which causes a sharp physical pain to unprotected ears.

No marked influence on engine thrust was found; however, the tendency was towards increase of thrust due to improved combustion efficiency. For instance, with intense screech an increase of about 5% in thrust was measured.

The experiments showed further that the reheat flame holder or stabilizer plays a most important part in exciting transverse gas oscillations. Its size was found to be critical. In other words, screech can be excited only when the stabilizer blocks a sufficiently high percentage of the tail pipe cross-sectional area. The shape of the stabilizer is also very important since some configurations are more prone to screech than others with the same blockage area. The transverse gas oscillations which cause screech were found to originate close to the stabilizer trailing edge. It is assumed that vortex shedding from this edge is the origin of these oscillations. The discovery of the important role of the reheat flame stabilizer opened the way for successful work on the second objective of the investigation – the prevention of screech.

Figure 1 shows a full scale rig for the investigation of screeching combustion under screeching conditions. The luminosity in the photographs is caused by the reflection of the flame on the water spray used for cooling the exhaust of the test rig. The observer is shown wearing ear defenders developed and designed by the Acoustics Section of the N.R.C.

In determining the drag of different flame stabilizers, the conventional method for measuring "cold loss" by the engine test bed thrust-meter was not sensitive enough to measure small differences in drag. A special balance, shown in Figure 2, was therefore made on which the stabilizers could be mounted and the drag measured directly. The reheat pipe is shown split apart to display the details of the arrangement.

H. Wisniowski
Engine Laboratory,
National Research Council

THE GUIDED MISSILE AS A SYSTEMS ENGINEERING PROBLEM

*Continued from Page 9**

GUIDED MISSILE SYSTEMS ENGINEERING IN THE LARGE

The biggest influence on the systems engineering of the missile proper is its relationship to the remainder of the total system. We can best continue discussion of guided missile systems engineering by broadening our sights to view the entire missile system.

The missile support system and logistics problems

A guided missile system cannot be designed and developed without the simultaneous design and development of a host of supporting equipment. Maintenance, logistics and over-all systems reliability are paramount factors. Thus, the surface-launched missile, intended to carry a payload for a long distance, must have a base and a communications system. Maintenance of the system, in the sense of both readiness and operation, often exerts a major influence on the design. The development and maintenance of the missile proper constitute only a fraction of the total system cost.

The complexity of the interrelationships can be brought out well by considering a nonmilitary example in airline navigation and traffic control. Here, clearly, we are moving towards higher densities, a wider spectrum of speeds from the low velocity helicopters to jets, operation in all weather conditions and a larger number of terminal points leading into other terminal points. Semiautomatic control of the system is certain to be approached. The pilot will be a necessary but less primary member of the total equipment team, which will include many communications devices, computers and radars; and the operation will be controlled by fairly complex rules that will require coordination by numerous governmental and private agencies. The moving vehicle must be designed so that it can operate with the system, but if all of the classes of equipment required were lined up for inspection, it would be obvious that the vehicle is but a part of the total system.

Human participation in the system

A complicating factor in guided missile systems engineering in the large is the relationship between men and machines. While we might be able to quibble in connection with the missile itself as to the exact importance of the man, especially if he is left out, no major complete guided missile system is intended for uninhabited operation. We hope that it is still true that guided missiles are our slaves rather than the other way around; therefore, we always design the guided missile system at large so that human beings still have a role to play. From the beginning, these assignments must be labeled and estimated as to cost, performance, stability, and time for development. Hopefully this is done just as clearly as we list the inanimate portions of the system and subject them to analysis. We are on weaker ground here, of course, and are less confident that we can extrapolate from some simple laws of nature. Laws of man's behavior are somewhat more difficult to clearly set down than, say, the law of gravity. On the other hand, we have had a lot of experience with human beings. In some situations, we can, for example, unhesitatingly reject a proposed guided missile system because it asks too much of the human beings in the system. (In contrast, for other situations, we may find it more difficult to accept or reject the system on the basis of doubts about some relatively simple electronic component, say, for example, a transistor.)

We have had many decades of experience with the extension of man's muscles by the machine. Here it is a matter of good engineering, in situations that require seemingly only the expenditure of energy or the application of a force, to properly match man's ability to that of the machine. Thus, ideally, we do not have a man digging a ditch; we have him steering the device that does that digging. Man is capable of subtle motions and the application of complex forces. He should be reserved for such situations. Where pure force magnitude alone is required, man is limited and is better replaced by machine.

Something similar is indicated in the extension and replacement of man's senses. No computer or thinking machine in existence or practically contemplated has a total capacity that can come close to that of man's brain. It would be absurd, then, to try to replace man by a completely automatic system in every conceivable situation in which he uses his brain or his senses. But, again, man's remarkable system is being misused if he is given easy assignments to do – too easy, really, for the tremendous powers of his brain and sensing system – and where the total quantity of operations may be physically beyond the man or perhaps tedious to an extreme. Thus, consider a constant decision-making operation in which there is at most the need for deciding amongst two or three possibilities, speedily identified but coming at a rate of thousands per second. This is simultaneously a job too simple for the human system and yet, in sheer quantity of simple actions per unit time, well beyond the human's ability to operate at all.

*Canadian Aeronautical Journal, January 1957.

The degree to which a system is to be made automatic, the specialized education and training required for the human operators, and the extent to which the human eyes, ears and brains will be used as participants in this system, are all considerations that play a major part in systems engineering in the large. The procedure is, to some extent, straightforward. We must visualize what actions need to be performed in the system; we must ask throughout whether they are best performed by a one hundred and fifty pound man or by some other total weight of automatic apparatus. We must compare the abilities, the investment, the maintenance and the reliability of these alternates.

Information and energy flow in the system

An interesting part of the detailed system engineering of a large, complex set of physical equipment and human elements is the tracing of the operation of the complete system with some sort of a flow chart. In general, such a chart can be conceived of as one of two classes. It is either an "information" flow or it is a "mass or energy" flow. To explain these two flow concepts and how they can be used to aid the systems engineer, it is well first to declare this categorization as somewhat arbitrary. For example, we might conceive that an electric power distribution system is in the second class. It distributes energy. The objective of the entire system is to make possible the creation of energy in electrical form and the distribution of that energy to countless potential terminal points with safety, stability and reliability. In a telephone system, on the other hand, the objective is to make possible the flow of information from station to station. In both instances, the flow of electromagnetic energy is fundamental but it helps greatly to look at the systems from these two somewhat different viewpoints.

We can illustrate these two concepts by some examples. Imagine that we are preparing a payload that can be launched out and into space and to return unharmed. We omit for the moment the question of precision in control of the flight, which carries with it the notion that we have information at all times of proper quantity and precision to make such control possible, and concentrate only on the energy dissipation throughout the process. We are concerned first with observing the kinetic energy of the payload as it gathers speed; during the entire flight the question of heat balance is continually observed and we watch the decelerations. We trace its history, in other words, from take-off to landing and throughout we are concerned with energy and matter. Our flow would show inputs and outputs from various sources, sources of higher kinetic energy from the propellant burning and higher temperature from aerodynamic heating.

A somewhat different kind of flow pattern is obviously indicated if we trace the flow of orders and directions in a defense system, starting with the early warning, processing of information concerning the existence and location of targets, and signals that initiate the defensive guided missile action and that observe and guide the operation to its completion. Here the flow diagram shows inputs of all kinds in the form of signals, some good and useful and others noisy but unavoidable, that enter and mix into the total flow. One can consider the entire operation from a base of information and communication theory. Everything that happens constitutes a set of observations and a processing of the information to obtain still more information which actuates the system. The system's motions that are continually observed and recorded give rise to additional information which feeds into the system. In a sense, it is incidental that there is a target, that it moves and that it is eventually to be intercepted by a guided missile which moves. All of these motions are merely manifestations of a successful transmission about the system of the messages which are the central core of the operation.

Again, the other mode problem

We have already discussed, in connection with the missile system proper, the fact that the systems engineer must be prepared for the system to operate in modes other than those which he desires, with a broadened concept of instability being a prime example of such other modes. This problem is much enlarged when one considers the complete guided missile system. This increase is not only because there are a large number of additional feedback loops in the over-all system as compared with the missile proper, both in the information flow or in the energy flow picture. Wherever there is feedback, of course, there is the possibility of oscillation, and what happens in one part of the system can cause effects elsewhere. There are some additional complications as well.

One of these has to do with the inputs from the human elements in the system – a more likely occurrence when we consider a very large system with numerous human components throughout. Even if the operators do exactly as they are supposed to do to insure good working of the system, the existence of feedback will introduce the possible problems of "hunting" and with it deviations from the selected mode of operation and the possibilities of saturation or complete malfunction. Presumably, if we have done a good job of matching man and machine in the guided missile system, we have introduced a human element only when what is expected of that element is sufficiently complex, yet uniquely suited to the time delays and responses of the human system, so that it is far better to employ a man than to replace him with what would presumably be tremendously complicated equipment. This usually means that the number of possibilities governing what the human operator will do is very large.

A telephone engineer recently cited an example of this kind when he said that in an automatic dialing system it is necessary to analyze what will happen in the system if the wrong number is dialed, if a nonexistent number is dialed, if the caller hangs up before the called party answers, and a host of other possibilities introduced by the human operator. These are not instabilities; they are not other modes of operation in the sense that feedback can cause hunting or build-ups to saturation. They are simply possible modes of operation which the system's many parameters allow to occur. If these situations exist with regard to the possible injection of interesting extra modes in the telephone system by human operators, it does not take much imagination to see what could happen in a guided missile system in which very expensive missiles can be incorrectly launched or launchings can

be held and aborted because of misunderstandings in dissemination of information amongst the human operators, each making his own determination and adding his own input.

Nonlinearity

Conventional feedback or servo theory teaches us how to analyze the input-to-output relations for an information or energy network of interconnected elements. But generally these analytical approaches are of practical use only if two conditions exist: the system should be linear, and the system should not have too many feedback loops. In discussing systems engineering in the large, neither of these conditions applies in general. To say that the system has a large number of interconnections and feedback paths is certainly an understatement for a typical large and complex system. Also, to say that it is always linear is a dangerous premise if one simply introduces the human element as a factor in the system.

Nonlinearity occurs whenever some part of the system has limiting values or stops. Ordinarily, in designing for linearity, we arrange for the characteristics of any force producing mechanism, or instrument that is to be read, to operate far enough away from its ends so that there is no danger of saturation or sudden cutoffs. In guided missile systems, we cannot so often afford this luxury. As an example, for the maneuvering of a missile we may find it entirely sensible to allow the control surfaces to be hard over some of the time. To do otherwise would mean creating much larger surfaces, thereby adding to the drag and the total structural weight. Weight, shape and physical integration problems tend to require the use of everything that we possess, even if some of the time there is an overloading condition. The guided missile system designer is often forced to work near the boundaries of operation of all the equipment and it is generally true that the operation of a system is not linear near the fringe region.

Typically, for instance, radar systems will commence to pick out, with vagueness and uncertainty, targets that are far away. We have a choice of ignoring these early inputs and having the system operate only on the basis of the more certain, later information that exists when the vehicles are closer and signal is stronger compared with the noise, or accepting the doubtful advance information and trying to make it additionally helpful. Generally speaking, it is advantageous to accept the early "rumors", especially if we can design so that it is within our discretion to believe them or not.

In a linear system, we can usually draw a flow diagram for the message or the information with an output and an input and, of course, with the output varying in a complex way with the input, but with the ratio of the two not being dependent upon the size of the input. A guided missile system is, generally speaking, too complex to describe in this way, if only because of the initial requirements we put upon it. For example, in a guided missile system, we may have alternate desired modes of operation as a function of the size of the input. Thus, if the guided missile system is a defensive system, some of the earlier components of the system that process the input information as to the targets may act more as a sorter than as a system that processes the information with linear components. There may be one plan of operation if the targets are high, and another if they are low – one type of operation of the entire system if the targets are few, and another if the targets are many, concentrated or widespread. To change to uniquely different modes of operation of the entire system, to implement only parts of it, and to do these as a function of the input data, both as to its magnitude and nature, is, of course, a highly nonlinear process. Some day I think someone will prove the theorem which holds that, as the situations to be handled become more complex, optimum design requires the greatest departure from linearity.

The existence of nonlinearity and the existence of a tremendous number of feedback loops in the energy or information flow in a systems engineering problem in the large makes theoretical analysis difficult and complicates the testing problem. We shall discuss in a moment the problem of testing, but it is well to call attention to the fact that these problems are difficult enough that the systems engineer is forced to consider departure from optimum to favor linearity and to minimize the number of feedback loops in the system. Quantitative comparisons are needed of the gain made by adding a feedback loop with the complexity of unwanted modes that comes from having it present. Given two alternate systems approaches that are otherwise equal, the one that deserves favor is that which lends itself more easily to analysis.

Optimizing and operations research

If a large guided missile system exists, either on paper or in actuality, it is possible to do research on its operation with the idea of optimizing its performance. If the design is on paper, this implies that we are doing the optimizing either to firm up its design or perhaps to compare that specific approach, when optimized, with some other alternate optimized approach. If the system already exists, we can still do operations research on it to improve our understanding of its behavior and, hence, to operate it closer to its optimum performance or perhaps to show how to alter it so that it will be a better system. Operations research is something that should be done by the systems engineering team; and systems engineering is never complete without some operations research having been done. The fact that it can be carried out on large systems, even after the systems have been brought into being, has suggested to some that there is no relation between systems engineering and operations research. I believe that it is better to let the words "operations research" be almost self-defining and to acknowledge that good systems engineering involves doing operations research.

It will not do, in attempting optimization of a guided missile system, to optimize the individual subsystem components in isolation, or, at the other extreme, to assume that no value at all can be obtained from such isolation and that the entire system must be optimized at once or not at all. By careful attention to the nature of the individual subsystem parts and of interaction, it is possible always in some instances to isolate parts and optimize them independently, with logical evidence that this optimization is a part of the optimization of the whole, while in other instances if the interaction were omitted the separated optimizations would be meaningless. The major problem in optimization of a guided missile system

is not encountered in the difficult optimization studies themselves, but in identifying the individual subsystems that can be separately optimized and identifying the areas where interaction overrides and only the combination can be optimized. One of many reasons for this statement is the assumption of availability of machine calculations to do the detailed optimizing.

In virtually everything that has been brought up – optimization, statistical effects, nonlinearities, multiple feedback loops – the designer would have a hopeless and indecipherable mesh of confusing parameters unless he could make literally thousands or more paper designs, try numerous combinations, and thereby hope to predict the performance. The large-scale digital computer, making possible a huge number of engineering calculations in a reasonable time, is an obvious asset. What is less obvious is the skill required to program and set up the computation system that will really serve the systems engineer well. Those who are inexperienced in large systems engineering are continually amazed at the number of individuals necessary and the competence that these individuals must possess, to contribute a real service to the systems engineer.

Testing and simulation

One of the points to be recognized in large-scale computation is that analog, real time, simulation devices are oftentimes superior to large-scale digital computers in predicting the behavior of the system. A typical situation involves carrying through the operation of a complete guided missile system, including three-dimensional simulation of the flight, with large-scale digital computers tied in with analog devices and with some actual parts of the missile system participating in the operation. Thousands of "flights" can take place in this way with alternate settings of the main parameters of the system, with variations in design of major subsystems considered, and with quantitative comparisons as to the characteristics of the systems.

In many guided missile systems, the operation may involve an extremely short time of flight. The cost per second of true operating experience is so large that the many hours of flight time required for a true understanding of all the possibilities of the system and for a finalizing of its design would call for a hopelessly expensive number of flights, not to mention the over-all time period used for carrying through all of the tests. Trial and error analysis, optimization and debugging procedures, done exclusively on the final system itself, would be equally impractical.

American engineering is, to a considerable extent, based on the habit of trial and error experimentation. Conspicuous successes have resulted from working directly with an object, the design of which must be finalized, and learning its shortcomings firsthand, as well as adlibbing the necessary changes. This procedure has, indeed, worked well, but it is because in most instances the device is simple, already well known, and only a small advance is being made.

In missiles, each element of the system must be separately, independently tested and checked out as much as possible. We should leave to final systems testing little but the interaction problems. This is, of course, to some extent an idealistic goal but it is fairly fundamental to successful systems engineering. This rule cannot always be obeyed, however. Sometimes the pressure of circumstances brings together a large collection of untested items composed of individual breakdowns and shortcomings that are confused with interaction problems; much time and money is wasted in diagnosis of the ills of this very confused and sick system.

A second rule to follow is that of using a great deal of machine calculations to cover as many as possible parameter adjustment problems for comparing alternate settings or alternate choices of characteristics of the system. But this can be done basically only where, in effect, the relations amongst the various portions of the system are understood and can be expressed well enough analytically. Real time simulation is oftentimes easier and the actual use of some portion of the system, with simulators and computers taking the place of the remaining portions, is also an effective technique. Thus, a highly nonlinear element which has friction might be operated under nearly true conditions. A part that is highly susceptible to generation of noise because of vibration can be made to operate in a synthetic system while under vibration, while the rest of the system is replaced by computers and simulators. Noise can be injected by synthetic random signal generators. The actual physical seeker-head of a homing missile can be put on a table and rolled, turned and vibrated, while it is homing on an artificial moving target in the laboratory. Some aerodynamic constants can be obtained in wind tunnels, then introduced by analog simulation devices into the simulated flight of a complete guided missile. A portion of a complete system can be tried out with manned airplanes playing the part of a missile.

One of the problems in this kind of experimentation is to be able to understand enough about the workings of the system to think up good simulation. It is like trying to use an analogy to help understand a confusing problem, only to discover that, unless you understand the problem, you do not know whether the analogy is realistic. A conceptual way of controlling this kind of confusion is to recognize that the system that has been set up in the simulation laboratory is, to be precise, not the system in which we are interested. It is hopefully one like it and, by spending time with that similar system, we hope to learn enough to help us design a system in which we are really interested.

A special note is worth while of the added difficulties in testing and in working experimentally with guided missile systems in view of the absence of the human observer in critical parts of the system. A human being, for 100 to 200 pounds, provides us with a large amount of observation possibilities. Moreover, we do not discuss the idea of having a human observer without the thought of his coming back and being able to report – itself a tremendous advantage. The combination of lacking the human observer and having to rely entirely on automatic recording techniques, added to the fact that so often we are forced to destroy a vital portion of the guided missile system in order to test it, makes the guided missile system amongst the worst systems engineering problems that we could invent when it comes to testing. In fact, so severe is the problem of learning what is happening in a guided missile system that we are oftentimes forced to design a system partially around

the problem of being able to test it when it is completed. Earlier reference was made to the way in which the ability to predict the behavior of a candidate system on theoretical grounds gave it an advantage over its competitors and the same thing applies to the ability of a system to be tested.

THE ATTAINMENT OF GREATER SYSTEMS ENGINEERING SKILL

Having surveyed the nature of systems engineering, and particularly the nature of guided missile systems engineering, we must now give attention to the final topic. What steps can be taken to improve the methodology of systems engineering? To increase the numbers of good systems engineers?

We are in rapid transition today to a new world which threatens to be dominated by technological advance. New complex systems of interconnected apparatus and men are under development to expand our ability to travel, produce, make war, or entertain ourselves. The projects we take on are so huge, and often so upsetting to existing ways of doing things, that the arrangement-making problem is itself a challenge. The depth of these technological changes will influence the rules of society and the organization of nations. In some ways, it is fortunate, then, that there are some bottlenecks that limit the rate of change from our present civilization to the infinitely more technical one that looms.

The most effective speed control is almost certainly going to be the limited number of good scientists and engineers and, of all the technical disciplines, systems engineering will emerge, I believe, as the most severe constriction in the bottle's neck. At any rate, systems engineering, with its need for merging all of the technical specialties, must certainly involve a harder man-power problem than that of the specialized fields. During a transition period, while arrangement-making is probably a greater bottleneck than the shortage of scientists and engineers, systems engineering, of all phases of engineering, feels the greatest burden because of the close association between systems engineering and over-all management of large projects.

Systems skills and management

Obviously, a systems engineering team needs specialists in each field involved in that system. What is not so obvious is the qualification of the leader of each of these specialty subteams – for example, the head of the aerodynamics group. This individual must be basically a systems engineer, although his major field of endeavor is aerodynamics. He may know more about aerodynamics than any other specialized technical discipline, but he must also be a reasonably competent electronics engineer, propulsion engineer and even economist. Unless he has this breadth, he will fail to insure the connecting link between the aerodynamics group and the other groups. It is not sufficient to imagine that there is a separate, integrating group consisting of individuals who know nothing about aerodynamics, but who somehow can effect a connection amongst each of these specialized groups. Therefore, the leader of the aerodynamics group is difficult to find amongst the aerodynamicists and must have years of systems training or experience after having attained familiarity with the aerodynamics field. The breadth required is not going to be natural. The inherent inclinations he may have towards being able to encompass many different kinds of disciplines at once still need to be augmented by special training and experience in order for him to do his job properly.

There is another kind of specialist that will be found in a first-class systems engineering team, if indeed the word "specialist" can be applied. He specializes in a type of functional, analytical tool or method that is common to various engineering or scientific fields. For example, he may be particularly expert at stability as a concept and be familiar with all of the analytical and machine tools used to understand stability wherever it may appear in the system, either as part of the electrical system in the guidance or control, or in aerodynamics and structural problems. Or he may be an expert on random phenomena, equally able to analyze cumulative errors of the system, over-all accuracy, noise in the radar, or turbulence in the aerodynamics. This class of hybrid "specialist-generalist" is extremely valuable, again is difficult to find and train, but does much to insure that the various specialized fields of engineering are united properly.

We come now to the class of generalist who belongs to none of the groups but is busily engaged exclusively in synthesizing and influencing the work of the specialized groups. This individual is doubtless a graduate of one of the special technical fields but has ceased to maintain himself as an expert in its details. He definitely has enough knowledge in several of the important fields so as to be a leader in the mixing of the individual disciplines. At the head of these generalists is the top systems engineering manager. This individual must be broad in management as well as in the technical sense. It ought to be obvious that a director of a complex systems engineering project should be outstanding technically. The claim that he also must be a skilled manager hardly needs justification. Despite the obviousness of these points, it is not uncommon to find a confusion between the quality of breadth in an individual and the mere absence of a specialty. Sometimes a top technical job is directed by a completely nontechnical person because it is believed that he is in a better position to appreciate the sales and administrative aspects of the job, or because, in recognition of the close relationship between big systems engineering direction and the difficult arrangement-making problem, he is a "good mixer". It is sometimes claimed that this saves engineers and scientists for the primarily technical tasks. The end result, naturally, is just the opposite, since, with inappropriate nontechnical leadership over a technical project, engineering manpower below the leader is usually wasted.

No simple single formula exists for organizing a systems engineering effort. A competent systems engineering organization, having a variety of systems projects, will quite likely have in command of the various projects individuals of a corresponding variety of college academic degrees and earlier experiences.

The changing role of the scientist

The systems engineering team must have a strong central core of practical, experienced engineers who know the engineering art thoroughly and who do not have to start from fundamentals each time a part of the system must be designed. They know existing com-

ponents and they know what industry can do. An appreciation of the need for this core is quite well imbedded, because we are accustomed to doing the simpler engineering tasks in which this kind of engineering skill almost completely dominates, where mostly what we seek to do is a small extension of what has been done successfully in the past. Not so well appreciated is the need for a broader and more academic type of theoretical and experimental scientist. Our previous discussion has called attention to the fact that most large systems are basically too complex to lend themselves to complete, quantitative analysis and yet it is vitally important that we bring ourselves as much as possible out of the speculative or qualitative type of approach. The system is also too large, complex and expensive to engage in hit or miss experimentation as a technique for somehow making it acceptable after it has been built. This means that a high-grade scientific effort is necessary also to devise crucial experiments on the weakest parts of the system and ingenious simulation of the whole system in the laboratory, all to the accompaniment of deep over-all mathematical analysis of the system, limited as these analyses must be in some areas because of lack of enough exact knowledge of some of the parameters.

Fortunately, for the future of systems engineering, the role of the outstanding scientific man is apparently undergoing considerable change. A major factor in the changing role of the scientist, and perhaps the most significant one of all, stems from the increasing acceptance by the scientific world of the importance of technology during their lifetimes. We used to be able to make easy distinctions between those scientists whose motivation is to understand nature better and those whose objective is to create something that has never been created before. The first group is not at all concerned with applications. A scientist in this group obtains his satisfaction from a conviction that his contributions in furthering man's knowledge of the universe will be significant, regardless of whether or not evidence appears during his lifetime that the knowledge he has added has been used by man to better himself. Scientists in the second group, typically the industrial physicists and the engineers, take pride in applying scientific knowledge to a specific objective. These two areas of scientific effort, both here to stay I hope, are now becoming diffused into each other. This is not merely because every kind of scientist appreciates that he is needed for urgent military projects. It is not even because the new systems tasks we take on offer such scientific challenge. When a collection of man-made devices are new and complex enough, then this new "man-made" nature requires the same scientific tools and abilities and offers the same satisfactions for its exploring as "free-state" nature. There is something more fundamental.

The motivation of an individual scientist is based considerably on what he considers significant. We have reached the point in our knowledge of science where man, by applying the discoveries of science, can radically change the world during the scientist's lifetime. Are we indeed on the threshold of space conquest? Are we really going to replace and extend man's brains on a wholesale scale in the coming decades? Are we on the verge of being able to generate so much damage so quickly as to virtually destroy a substantial part of the civilized world in a few seconds? If so, is it more significant to study nature's laws, ignoring man's close linkage to them, or is it more significant to study the potential of man-made changes in our world? What man can accomplish to alter the world is perhaps the most important of all aspects of nature. Even if the study of what man can do may not be more significant and may not deserve higher stature than the study of nature's additional secrets, it certainly has begun to compete with it.

Tools to be taught

The commonest suggestion with regard to the teaching of systems engineering is that it be done by the case-study method. This method is a good one, and probably will always be an important part of the teaching of systems engineering. Too much dependence on the case-study method is an admission that we do not yet have systems engineering established as a field of endeavor, with its philosophy of approach and with its special tools. The philosophy problem is a difficult one, especially if one considers that the problem is systems engineering in the large. One really is asking for an answer to the question of how to go about doing big and complex things in life. Yet there is no question but that an individual seeking to become expert in systems engineering can profit by formal courses in philosophy and logic. Clear thinking in comparing alternate approaches, trying to pin down objectives, and seeking to understand the consequences of doing a job in relation to what already exists — it is with just this kind of problem that the studies in philosophy and logic are supposed to help us. Engineers now need to make a bridge between these formal mental disciplines, which we normally do not study, and our new systems engineering responsibilities.

Meanwhile, however, it is certainly possible to list various tools that can be studied, which are more important in systems engineering than they are, generally speaking, in individual specialized technical fields. Thus, the physical sciences and mathematics should be studied with greater thoroughness by the would-be systems engineer than is customary for the average engineering degree. Special selections in the field of stability, statistics and random phenomena, large-scale computers and simulators, information theory and energy transfer can be cited as examples. By sufficient study of past examples in systems engineering, a new course in statistical phenomena could be arranged which emphasizes that kind of probability theory that comes up most frequently in large systems analysis. Similarly, the problems in the stability course would emphasize systems with many modes and complex feedback loops. Game theory and information theory could be taught with emphasis on examples taken from large systems engineering problems. Maxima and minima problems, linear programming and other mathematical techniques selected with systems engineering in mind would yield courses which, in detail, are different from those generally available.

One question that arises is whether or not systems engineering should be taught on a level with other branches of engineering, such as electrical, mechanical, or aeronautical engineering, or whether systems engineering basically is a graduate program. It is desirable, to achieve the end result of the university course intended to

prepare the individual for systems engineering, that he be unusually well grounded in the fundamentals, have a better appreciation of all of the technical fields than the average graduate and, in particular, be acquainted with the tools that oftentimes are needed in systems engineering. He probably should do a systems engineering thesis, but I am afraid that he will lack the ability to make the grade in relation to all this unless he takes on one specialty somewhat more seriously than the others and uses it as a vehicle for gaining strength in his appreciation of engineering and science. It is somewhat arbitrary whether he should study that one specialty with greater emphasis early and then later add to his appreciation of the rest, or vice versa. I can imagine either possibility working out well as a function of the individual student, the individual teachers available, and other such local details; but it looks as though a systems engineering education will require more than four years.

Industrial apprenticeship

It may have to be conceded that systems engineering requires so much case-study training for ideal results that a university course can never do as well by systems engineering as it does by, say, physics or electrical engineering. First of all, it is not easy to select those students who really are properly suited to systems engineering. This selection may have to come after additional years of performance and reaction to systems engineering tasks. Even if the universities turn out systems engineers in the future, there is no question but that industrial training and apprenticeship will be even more necessary in systems engineering than it already is in the various other technological fields.

Most important in industry is the problem of finding the good systems engineering candidate. I believe that there is considerable similarity between executive ability and systems engineering ability, although they are far from identical abilities. An outstanding technical man who appears to be good in organizing and supervising a fairly large technical effort can probably be made into a good systems engineer. In his individual case, one must look at the shortcomings of his education and background and arrange by appropriate assignments for him to acquire the additional tools and experience. Years may have to be invested to create a first-class systems engineering leader.

Of course, there are more mundane and obvious considerations. Industrial organizations should seek relationships with universities to create courses to teach the special tools so common in systems engineering. They should rotate certain of their specialists amongst other specialty groups so as to try to create individuals who have an understanding of more than one field.

However it is done, industrial and university cooperation is essential to improve systems engineering and, even with this effort, systems engineering will probably finally control the rate of transition from our present society to the coming more technical one.

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FLIGHT TESTING OF HIGH-SPEED AIRCRAFT†

by C. E. Myers, Jr.*

Convair Division
General Dynamics Corporation

THIS paper is directed to those who share the responsibility of determining the flying qualities of today's high speed aircraft.

I will present a review of practices and methods which have aided in expediting the flight testing of a few high speed military airplanes. I will describe the steps which were taken in preparing for the spin recovery demonstration of a high performance delta configured airplane. In addition, I would like to remind you of the most prominent problem facing the test pilot of today's high speed airplanes.

In the United States, a most important step has been taken toward expediting the flight testing of military airplanes. A plan known as the "Accelerated Development Test Program" has been put into effect. This program calls for simultaneous allocation to the development agency of numerous airplanes for use as test vehicles. A few tests for which individual airplanes have been allotted are:

(1) Stability and Control
(2) Performance
(3) Armament
(4) Electronics
(5) Heating and Ventilating
(6) External Stores
(7) Spin Demonstrations
(8) Flight Loads Analysis
(9) Flutter Analysis

The program produces a continuous flow of data to the analysis and design groups. This flow of information from the various test vehicles is continually being assembled to form an increasingly clearer picture of the airplane's faults and virtues. The designer's dilemma, wherein he often created future problems while attempting to correct the present troubles, has been alleviated.

At Convair, the trend toward specialization and simultaneous assault has been applied to the utilization of flight test personnel. A complete team is assigned to each of the many test vehicles. Each team is a unit composed of mechanics, electricians, control engineers, an instrumentation engineer, a flight test engineer and an engineering test pilot. The team concentrates on the one airplane and test program assigned to it. The "Accelerated Test Development Program" and the "Flight Test Team" concept have proven to be a profitable combination, both to the manufacturer and the customer.

The flight test methods which are utilized by any particular organization are dependent upon the facilities and equipment available. The test methods I will review are dependent upon the utilization of photo panels, oscillographs, telemetering, magnetic tape recorders, analog computers and pilot voice recording equipment.

AIRSPEED CALIBRATION

Calibrating the airspeed indicating system at high altitudes of an airplane which has a much higher maximum speed than any available pacing vehicle is a common problem. One solution involves utilizing a well calibrated pacer aircraft but in a different manner than is normally employed.

The method is dependent either upon flying the pacer at an altitude where contrails are produced or equipping the pacer with smoke generating equipment.

The pacer, with the test airplane beside it, is stabilized at subsonic speed at the desired altitude where it is either creating a contrail or emitting a smoke path that is clearly visible to the pilot of the test airplane. The test airplane is then flown along the edge of the contrail, decelerating gradually from the speed of the pacer to the minimum speed desired. During this run, the pacer airplane pulls well ahead of the test airplane. The pilot of the test airplane applies maximum power and accelerates along a path close to the edge of the smoke trail until V_{max} is obtained. At this time the test airplane should again be near the pacer. The acceleration run is followed by another deceleration run which completes the picture.

Throughout the run, the photo panel of the test vehicle is operating at 16 frames/second while the pilot of the pacer is maintaining constant altitude, stabilized flight.

Utilizing the same data reduction method as is used for "tower fly-by" calibration, the altimeter error and hence the airspeed indicating error of the test airplane is easily determined.

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*Engineering Test Pilot.

LONGITUDINAL STABILITY, STATIC, CONTROL FIXED AND FREE

The contrail or smoke trail and acceleration/deceleration methods may also be used to advantage in determining the longitudinal stability characteristics.

The airplane is again accelerated and decelerated along a level trail throughout the desired speed range while trimmed for some pre-determined intermediate airspeed.

During the run, IAS, altitude, stick force and elevator position are continually recorded by photo panel, oscillograph and/or telemetering.

The purpose here, of using the smoke trail, is to avoid chasing the usual altimeter error and transonic altitude jump. Should the test airplane have little static source error throughout the desired speed range, the test can be performed without the aid of the pacer and smoke trail.

The data reduction involves a straightforward plot of the various stick forces and elevator positions as they occurred during the acceleration and deceleration runs.

LATERAL-DIRECTIONAL STABILITY, STATIC AND DYNAMIC

Static and Dynamic Lateral Directional Stability characteristics can be determined by utilizing the transient side-slip method.

For this test, the airplane is instrumented so as to record control force, control position, bank angle, yaw rate, pitch rate, roll rate, IAS and altitude.

The pilot merely stabilizes at the desired airspeed near the test altitude and creates progressively larger steady-heading sideslips in one degree increments, pausing at each point long enough to establish a no turn condition. Upon reaching the maximum side-slip angle, he pauses and then releases the controls and allows the resulting oscillations to fully damp.

Data reduction is accomplished by plotting the relative aileron and rudder forces and position for each increment of side-slip to establish the static characteristics. The dynamic qualities are obtained from a plot of the oscillations which followed release from the maximum side-slip.

AIRPLANE DAMPER SYSTEM IMPROVEMENT

Tests which require repeatable brief airplane oscillations are most rapidly and accurately accomplished by the use of a technique which is common to the field of testing guided missiles. I refer to the programmed pulse. This method utilizes the damper system of the airplane to create the pulse. The period, amplitude and frequency of the disturbances are preset into a black box. The pilot has merely to stabilize the airplane and press the programmer switch. The ensuing oscillations are recorded by oscillograph.

The advantage of the programmer is that it produces repeatable, properly timed disturbances more accurately than could be expected of a human.

ROLL COUPLING

The combination of mass distribution and directional stability of a few high speed fighters has produced rather distasteful results in the form of excessive sideloads and lateral and normal accelerations during rolling maneuvers. This phenomenon has become referred to as "roll-coupling".

The possible outcome of such loads dictates that a cautious but thorough investigation be conducted to determine the magnitude of the loads which occur during maximum rate rolls of a fighter type airplane. The method used in the roll-coupling tests of one highly susceptible airplane not only afforded the maximum in safety but simultaneously decreased the amount of flight time normally required for such a test.

Prior to beginning the flight tests, the probable result of the roll maneuver, insofar as lateral and normal acceleration were concerned, was calculated by an analog computer; these results were plotted as they would appear on telemetering records. A sample flight test for non-critical points was performed and the actual result was compared with the predicted result. Corrections were made based on the comparison and the problem was recalculated.

The recomputed data was considered to be reasonably accurate and flight tests continued.

Utilizing the ground monitoring capability of telemetering, the Flight Test Engineer and the Dynamicist made simultaneous comparisons of the predicted loads and the loads as they occurred during the maneuver. In this manner, the flight test program progressed rapidly, the pilot being allowed to proceed from point to point without fear of exceeding the limits of the airplane. The usual delays between points, while pilot and engineer await data analysis, were avoided. The program was brought to a conclusion rapidly and safely.

FLUTTER ANALYSIS

The task of determining the aeroelastic behaviour of a delta wing was approached by Convair in a conventional manner. It was decided to employ the Sinusoidal method of vibration excitation. Inertia vibrators were obviously the most practical means of producing the desired excitation. The standard rotary unbalanced shaker was considered, but was found to be unsatisfactory since immediate stoppage was not possible – a feature which is necessary for vibration decay studies. An hydraulically powered, electrically controlled piston type of rocker was developed which not only provided excitation for frequency sweeps but could be immediately stopped for decay sweeps.

One shaker and three pickups were installed in each wingtip and in-flight records were obtained with an airborne magnetic tape recorder. Multi-channel tape recording was used because it has the advantages of built-in filtering, repeatability and assures no channel overlap or interlacing of traces.

SPIN TESTS

The most interesting phase of a flight test program is the determination of the spin characteristics.

The spin recovery demonstration of a fighter type airplane must be approached in an orderly manner. Consultation with test pilots who have recently conducted spin recovery of other high performance airplanes is very worthwhile. Observation of the spin characteristics

of a model of the test airplane in a vertical wind tunnel is considered a prerequisite.

The spin characteristics of two recent airplanes indicated a tendency to spin in a flat attitude. The tunnel tests also revealed the spin axis to be well behind the cockpit. The rate of rotation and spin attitude, coupled with the distance between the spin axis and the cockpit, produced previously unencountered centrifugal loads on the pilot.

Environment during such a spin was simulated in the University of Southern California's centrifuge where pilots were subjected to transverse loads up to five g's. Such loads resulted in pooling of body fluids in the legs, feet, arms and hands. This pooling of fluids in the extremities produced considerable pain after only a few seconds at the higher accelerations. In addition, the pilot found it difficult to prevent his head from falling forward as the load surpassed three g's. The pilot's vision was impaired and the confusion factor increased to the extent that he could not be depended upon to react properly to the situation.

Anticipating the worst possible conditions, the following items were incorporated to aid the pilots in successfully performing the spin demonstrations:

(1) *Transverse Anti-g Suit*
   (a) This suit resembles a partial pressure suit without the torso pressure provisions. Air tubes run to the wrists and ankles. When these tubes are inflated, the tightening of the suit decreases the pooling of fluid in the extremities.

(2) *Body Retention Strap*
   (a) This is a wide band which passes from one side of the seat, across the pilot's chest, to the opposite side of the seat.

(3) *Head Restraint*
   (a) Head restraint is provided without undue restriction to head rotation by means of an adjustable dacron strap attached to the sides of the pilot's helmet. The strap loops around a vertical roller which is mounted in the ejection seat head rest.

(4) *Altimeter*
   (a) An altimeter was installed which covers the entire test altitude range with less than 360° of indicator movement.

(5) *Spin-Chute*
   (a) Stowed at base of the vertical fin.
   (b) Can be jettisoned under any condition.
   (c) Diameter and length of risers were determined by spin tunnel tests; for airplanes of radical design the formula found in AGARD is invalid.

(6) *Anti-Spin Rockets*
   (a) 1000 lb-thrust rockets were located near each wing tip. Firing the correct rocket decreases the rate of rotation.

(7) *Recovery Lights*
   (a) Two amber lights were located at outboard extensions of the instrument panel to signal the pilot which direction to apply the aileron or which rocket to fire for recovery.
   (b) In addition to the rocket "fire" switches, the pilot was provided with a means of neutralizing the rocket within 1/100 of a second.

I would like to shift from the discussion of the means by which we determine the flying qualities of our high speed aircraft and focus for a moment on the personal problem facing the man who must collect the data.

ESCAPE SYSTEMS

A major portion of the flight testing of today's high performance aircraft is necessarily performed at supersonic speeds. One might wonder whether or not this increase in velocity at which the pilot must perform his mission has increased his apprehensions or fears — after all, he is still comfortably seated within an air-conditioned, pressurized enclosure, surrounded by gadgetry which at the flip of a finger will answer many of his desires. The truth is that the pilot's apprehensions parallel the gradient of aircraft performance.

The most prominent problem which the pilot of high speed airplanes must face is the fact that successful escape from the aircraft at supersonic speed is not assured.

Before going further, perhaps a definition of "successful escape" would be in order. Some have defined a successful escape system as one which "will provide for separation of the pilot from the airplane in such fashion that he does not sustain irreversible physical damage". In other words, the pilot who ejects from an airplane at high speed and, as a result of the ejection, sustains such damage that he must be hospitalized for physical repair has successfully escaped.

My definition of a successful supersonic escape system is one which "will effect separation of the pilot from the airplane and lower him to earth in such condition that, after making contact with the surface, he will be immediately able to begin walking or swimming towards the nearest habitation".

This is not demanding too much; only a few years ago successful escape, as per my definition, was quite common.

Although there has been a definite lag in development, the U.S. Air Force and industry are cognizant of the problem. Priority contracts for the development of high speed pilot escape systems have been awarded to Convair and Lockheed, both of whom have a personal interest in the subject.

Diverting such formidable engineering forces toward the design of a successful escape system is the action that has been long awaited and should produce the desired result.

REMOTE CONTROL TESTING

The same realization of the pilot's dilemma, which was cause for diverting a substantial engineering force to develop a high speed escape system, has given strength to those who propose remote control testing for portions of a development program which are considered unusually hazardous.

It is true that remote control testing would relieve a great deal of pressure from the pilot and if all the black boxes performed as desired the test maneuvers

would be conducted exactly according to plan. Opposing remote control testing is the expense and time required to perfect each component of the control system, since nothing short of 100% reliability could be acceptable. The thought that tests could proceed rapidly without the usual build-up programs is far from true. The fact that the machine is a complex, expensive, practically irreplaceable test specimen will force the engineer to proceed as cautiously as though a pilot were at the controls for each flight. Finally, it is the consensus of those with whom I have discussed this question that experienced test pilots will take necessary calculated risks for a worthy fraction of the cost of a remote control system and will guarantee to complete the tests in less time than would be required for remote testing.

CONCLUSIONS

I have presented a brief review of the high speed testing methods being utilized by a portion of the industry. It is felt that these methods represent the most expeditious means of accomplishing the task.

I offer four general rules for expeditious flight testing of today's high speed aircraft:

(1) Allot sufficient airplanes to the test program.
(2) Instrument completely but demand no closer tolerances than are required for the data to be obtained, keeping in mind that reliability varies inversely with complexity.
(3) Insist on close coordination between Project Engineer, Flight Test Engineer and Pilot.
(4) Utilize test techniques which will yield the most data per minute of flight time.

Pilot escape is completely in the hands of our thinkers and designers. During the interim, the only course of action on the part of flight test personnel is to concentrate on conducting the tests in the most expeditious manner with special emphasis on safety.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute

will be held in the

CHATEAU LAURIER
OTTAWA

on the

27th and 28th May, 1957

The Programme, which is now being prepared, will include Sessions on

Noise, Materials, Aviation Medicine and Human Engineering, Aerodynamics, Anti-Icing and De-Icing, Flight Test, Design and Structures

as well as the annual Business Meeting.

This meeting affords an opportunity for the presentation of papers by members of the C.A.I. The Council is most anxious to encourage Canadian papers and hopes that any member wishing to contribute to any of the above-mentioned Sessions will submit a summary of his paper for consideration. Such summaries must be in the hands of the Secretary by the 28th February 1957.

VIBRATIONS AND DYNAMIC LANDING LOADS OF MAIN LANDING GEAR MOUNTED ON THE WING†

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SUMMARY

In this paper the aircraft is replaced by an equivalent vibrating system represented by the wings and the shock struts. For the two-wheel symmetric landing cases the solution of the problem is divided into three parts:

(1) the composition and solution of the frequency equations for the equivalent vibrating system of the wing, rib and strut;

(2) the calculation of the generalized forces at the landing gear axles or bogie pivot;

(3) the calculation of the responses at the landing gear axles or bogie pivot due to the generalized forces for the natural frequencies of the system.

The dynamic landing loads for elastic aircraft are derived at the landing gear axle or bogie pivot in order to have proper loads for design and stressing of the undercarriage and fittings on the wing.

INTRODUCTION

Accident statistics for civilian and military aircraft show that the structural failures which are most numerous are those connected with the landing gear.[1] These are mainly due to vibrations of the wing and the shock strut excited by ground reactions during landing. In certain combinations of the flexural and torsional stiffness of the wing, flexural stiffness of the shock strut and geometry, there are vibrations which cause high accelerations in the concentrated mass of the wheels, brakes and tires in a fore and aft direction. In certain cases, drag loads caused by spinning up of the wheels give relief to forward acceleration of the above concentrated mass. This explains why most structural failures of landing gear or those connected with landing gear occur during normal landing on wet runways (low coefficient of friction between tire and runway before spin up – very high forward acceleration of the concentrated mass at tail down attitude). Unsymmetric landings may be another cause of vibrations and failure of landing gear or airframe in regions well removed from the landing gear itself. In brief the structural design of modern aircraft can not be based on semi-dynamic considerations of landing loads, i.e. treating the aircraft as a rigid body.

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DISCUSSION OF THE THEORY LEADING TO THE SOLUTION OF THE PROBLEM[2,3,4,5]

Ground reactions at the landing gear axles are derived from the dynamic equilibrium of the aircraft considered as a rigid body. This equilibrium is unaffected by the natural modes of vibrations, since the inertia forces in each normal mode are so distributed that the summation of the forces and moments for the entire aircraft is zero. For each particle, the inertia, elastic and external forces are in equilibrium. The external forces are balanced by the difference between inertia and elastic forces.

Each natural mode of vibration can be treated separately because the natural modes are orthogonal – they do not feed energy to each other or to the rigid body modes. This fact permits the determination of the natural modes experimentally.

The acceleration at any point of the structure is the summation of the accelerations caused by the rigid body motions and the vibrations in all the natural modes at that point. Only the fundamental and the first few modes are usually of importance. The higher modes are generally too high a frequency for the external load to have any effect other than a static one.

A particular natural mode of a continuous system, subjected to distributed inertia forces and elastic resistances, can be considered as a single equivalent mass and a single equivalent spring – the criterion of equivalence being that the force element does the same amount of work and hence has the same effect on the amplitude as it did before transference to the reference section.

COMPOSITION AND SOLUTION OF THE FREQUENCY EQUATIONS FOR THE EQUIVALENT VIBRATING SYSTEM OF THE WING, RIB AND UNDERCARRIAGE STRUT[4,6]

The wing is replaced by its flexural and torsional parameters, the ribs by its flexural parameters, and the undercarriage strut is replaced by n concentrated masses and its flexural parameters. The mechanism of the equivalent vibrating system is shown in Figure 1. Two cases are considered:

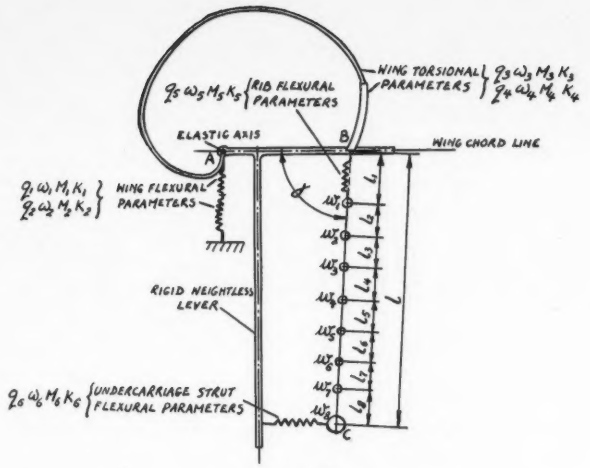

Figure 1
The mechanism of equivalent vibrating system

(1) the undercarriage strut is fixed to the rib which is built in at each end, and

(2) the undercarriage strut is fixed to the rib which is a cantilever beam built into the structural box of the wing.

Six degrees of freedom are taken into account along with the generalized coordinates to which they apply. The main parameters are given in Table 1.

TABLE 1

Generalized Coordinates	Uncoupled Modes	Natural Frequency	Generalized Mass	Generalized Stiffness
q_1	Fundamental symmetric wing deflection	ω_1	M_1	K_1
q_2	First harmonic symmetric wing deflection	ω_2	M_2	K_2
q_3	Fundamental symmetric wing torsion	ω_3	M_3	K_3
q_4	First harmonic symmetric wing torsion	ω_4	M_4	K_4
q_5	Fundamental undercarriage rib bending	ω_5	M_5	K_5
q_6	Fundamental undercarriage strut fore and aft bending	ω_6	M_6	K_6

The method of calculating the parameters of the above table is given in References 2, 3, 5, 6.

The system is referred to the elastic axis at the undercarriage station about which the rotation of the system takes place. The flexural modes of the wing q_1 and q_2 are always measured from the elastic axis perpendicular to the chord line of the wing in the fore and aft plane. The frequency equations refer to the rotating axes CZ and CX respectively, passing through the centre line of the undercarriage strut in its undeformed shape and perpendicular to it (Figure 2). It is assumed that point

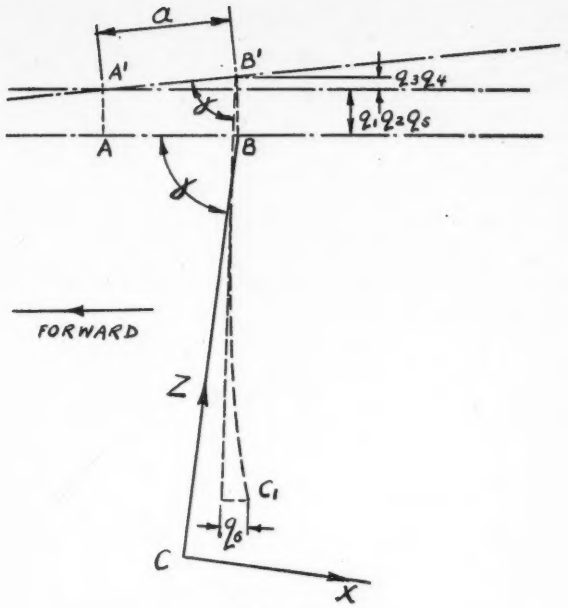

Figure 2

A, representing the elastic axis in fore and aft plane, and point B, which represents the fixing of the undercarriage strut to the rib, are displaced upwards during the initial stage of vibrations due to the vertical component of ground reaction, and that the wing is rotated anti-clockwise about point A due to the moment of the resultant ground reaction (its vertical and horizontal components).

Referring to Figure 3, if the displacement of point B vibrating in a certain torsional mode is q_T, and its linear velocity $\dot{q}_T$, then its angular velocity ω is:

$$\omega = \frac{\dot{q}_T}{a} \qquad (1)$$

Considering the concentrated mass of the undercarriage

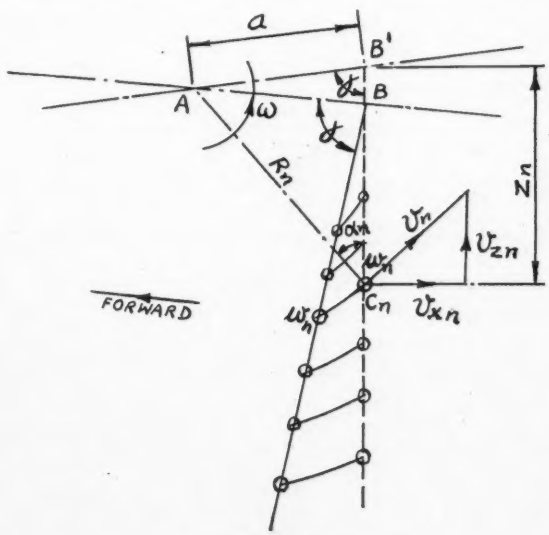

Figure 3

strut $\frac{w_n}{g}$, its linear velocity v_n is:

$$v_n = \omega R_n \tag{2}$$

From the triangle $AB'C_n$:

$$R_n = \frac{a \sin \gamma}{\sin \alpha_n} \tag{3}$$

Substituting Eqs. (1) and (3) in Eq. (2):

$$v_n = \frac{\sin \gamma}{\sin \alpha_n} \dot{q}_T \tag{4}$$

Resolving v_n along centre line of undercarriage strut v_{zn} and normal to it, v_{xn}:

$$v_{zn} = v_n \sin \alpha_n \tag{5}$$

$$v_{xn} = v_n \cos \alpha_n \tag{6}$$

Substituting Eq. (4) in Eq. (5):

$$v_{zn} = \dot{q}_T \sin \gamma \tag{7}$$

From the triangle $AB'C_n$:

$$R_n \cos \alpha_n + a \cos \gamma = l_1 + l_2 + l_3 + \ldots l_n = \sum_1^n l_n = z_n$$

$$\therefore \cos \alpha_n = \frac{z_n - a \cos \gamma}{R_n} \tag{8}$$

Substituting Eqs. (3), (4) and (8) in Eq. (6):

$$v_{xn} = \left(\frac{z_n}{a} - \cos \gamma \right) \dot{q}_T \tag{9}$$

If the flexural mode q_F of the wing or rib is referred to the rotating axes CZ and CX (see Figure 2), its components are:

$$q_{FZ} = q_F \sin \gamma \tag{10}$$

$$q_{FX} = q_F \cos \gamma \tag{11}$$

Since the flexural modes are always measured perpendicular to the chord line, and the wing is very stiff along the chord line, the deflection in that direction is assumed to be zero. The flexural mode (fore and aft) of the undercarriage strut q_s has no component along the CZ axis; its component normal to the centre line of the undeformed undercarriage strut q_{sx} is:

$$q_{sx} = \eta_n q_6 \tag{12}$$

where η_n may be taken from the diagram giving the mode of deformation of the undercarriage strut in fore and aft direction. At the axle $q_{sx} = q_6$.

Case 1–The undercarriage strut is fixed to the rib which is built in at each end.

Referring to Figure 2 and to Eqs. (7) and (10), the velocity of a concentrated mass $\frac{w_n}{g}$ of the undercarriage strut along CZ axis vibrating in all six modes may be written:

$$V_{zn} = (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5) \sin \gamma \tag{13}$$

and considering Eqs. (9), (11) and (12), the component V_{xn} may be expressed:

$$V_{xn} = -(\dot{q}_1 + \dot{q}_2 + \dot{q}_5) \cos \gamma + \eta_n \dot{q}_6 + (\dot{q}_3 + \dot{q}_4) \left(\frac{z_n}{a} - \cos \gamma \right)$$

$$\therefore V_{xn} = -(\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5) \cos \gamma + (\dot{q}_3 + \dot{q}_4) \frac{z_n}{a} + \eta_n \dot{q}_6 \tag{14}$$

The kinetic energy (T_n) of a single concentrated mass $\frac{w_n}{g}$ of the undercarriage strut can be written:

$$T_n = \frac{w_n}{2g} (V_{zn}^2 + V_{xn}^2) \tag{15}$$

Substituting Eq. (13) in Eq. (15):

$$T_n = \frac{w_n}{2g} \left\{ (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5)^2 + (\dot{q}_3 + \dot{q}_4)^2 \left(\frac{z_n}{a} \right)^2 + \eta_n^2 \dot{q}_6^2 - 2 (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5) \left[(\dot{q}_3 + \dot{q}_4) \frac{z_n}{a} + \eta_n \dot{q}_6 \right] \cos \gamma + 2 \eta_n \dot{q}_6 (\dot{q}_3 + \dot{q}_4) \frac{z_n}{a} \right\} \tag{16}$$

The kinetic energy of each concentrated mass of the undercarriage strut can be expressed by Eq. (16). The kinetic energy of the entire undercarriage strut composed of n concentrated masses may be written:

$$T = \frac{1}{2g} (w_1 + w_2 + \ldots w_n) (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5)^2 -$$

$$\frac{1}{ga} \cos \gamma (w_1 z_1 + w_2 z_2 + \ldots w_n z_n) (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5) (\dot{q}_3 + \dot{q}_4) -$$

$$\frac{1}{g} \cos \gamma (w_1 \eta_1 + w_2 \eta_2 + \ldots w_n \eta_n) (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5) \dot{q}_6 +$$

$$\frac{1}{ga} (w_1 z_1 \eta_1 + w_2 z_2 \eta_2 + \ldots w_n z_n \eta_n) (\dot{q}_3 + \dot{q}_4) \dot{q}_6 -$$

$$\frac{1}{2ga^2} (w_1 z_1^2 + w_2 z_2^2 + \ldots w_n z_n^2) (\dot{q}_3 + \dot{q}_4)^2 +$$

$$\frac{1}{2g} (w_1 \eta_1^2 + w_2 \eta_2^2 + \ldots w_n \eta_n^2) \dot{q}_6^2 \tag{17}$$

Substituting:

$$\frac{1}{g} \sum_{n=1}^{n} w_n = m_1 \tag{18}$$

$$\frac{1}{ga} \sum_{n=1}^{n} w_n z_n = m_2 \tag{19}$$

$$\frac{1}{g} \sum_{n=1}^{n} w_n \eta_n = m_3 \tag{20}$$

$$\frac{1}{ga} \sum_{n=1}^{n} w_n z_n \eta_n = m_4 \tag{21}$$

$$\frac{1}{ga^2} \sum_{n=1}^{n} w_n z_n^2 = m_5 \tag{22}$$

$$\frac{1}{g} \sum_{n=1}^{n} w_n \eta_n^2 = m_6 \tag{23}$$

the kinetic energy of the entire undercarriage strut may be rewritten in the form:

$$T = \frac{m}{2} (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5)^2 -$$

$$m_2 \cos \gamma (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5) (\dot{q}_3 + \dot{q}_4) -$$

$$m_3 \cos \gamma (\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5) \dot{q}_6 +$$

$$m_4 (\dot{q}_2 + \dot{q}_4) \dot{q}_6 + \frac{m_5}{2} (\dot{q}_3 + \dot{q}_4)^2 + \frac{m_6}{2} \dot{q}_6^2 \tag{24}$$

The potential energy P of the equivalent vibrating system is:

$$P = \frac{1}{2} (K_1 q_1^2 + K_2 q_2^2 + q_2^2 K_3 + K_4 q_4^2 + K_5 q_5^2 + K_6 q_6^2) \tag{25}$$

MATRIX 1

$$\begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \end{bmatrix} = \begin{bmatrix} \frac{m_1}{K_1} & \frac{m_1}{K_1} & \frac{m_1-m_2\cos\gamma}{K_1} & \frac{m_1-m_2\cos\gamma}{K_1} & \frac{m}{K_1} & -\frac{m_3\cos\gamma}{K_1} \\ \frac{m_1}{K_2} & \frac{m_1}{K_2} & \frac{m_1-m_2\cos\gamma}{K_2} & \frac{m_1-m_2\cos\gamma}{K_2} & \frac{m_1}{K_2} & -\frac{m_3\cos\gamma}{K_2} \\ \frac{m_1-m_2\cos\gamma}{K_3} & \frac{m_1-m_2\cos\gamma}{K_3} & \frac{m_1-2m_2\cos\gamma+m_5}{K_3} & \frac{m_1-2m_2\cos\gamma+m_5}{K_3} & \frac{m_1-m_2\cos\gamma}{K_3} & \frac{m_4-m_3\cos\gamma}{K_3} \\ \frac{m_1-m_2\cos\gamma}{K_4} & \frac{m_1-m_2\cos\gamma}{K_4} & \frac{m_1-2m_2\cos\gamma+m_5}{K_4} & \frac{m_1-2m_2\cos\gamma+m_5}{K_4} & \frac{m_1-m_2\cos\gamma}{K_4} & \frac{m_4-m_3\cos\gamma}{K_4} \\ \frac{m_1}{K_5} & \frac{m_1}{K_5} & \frac{m_1-m_2\cos\gamma}{K_5} & \frac{m_1-m_2\cos\gamma}{K_5} & \frac{m_1}{K_5} & -\frac{m_3\cos\gamma}{K_5} \\ -\frac{m_3\cos\gamma}{K_6} & -\frac{m_3\cos\gamma}{K_6} & \frac{m_4-m_3\cos\gamma}{K_6} & \frac{m_4-m_3\cos\gamma}{K_6} & -\frac{m_3\cos\gamma}{K_6} & \frac{m_6}{K_6} \end{bmatrix} \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \end{bmatrix} = \frac{1}{\omega^2} \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \end{bmatrix}$$

Applying Lagrange's equations of motion:

$$\frac{\partial}{\partial t}\frac{\partial T}{\partial \dot{q}_r} + \frac{\partial P}{\partial q_r} = 0$$

and substituting proper values from Eqs. (24) and (25), the following equations for the equivalent vibrating system may be written:

$$m_1\ddot{q}_1 + m_1\ddot{q}_2 + (m_1 - m_2\cos\gamma)\,\ddot{q}_3 + (m_1 - m_2\cos\gamma)\,\ddot{q}_4 + m_1\ddot{q}_5 - m_3\cos\gamma\,\ddot{q}_6 + K_1q_1 = 0 \quad (26)$$

$$m_1\ddot{q}_1 + m_1\ddot{q}_2 + (m_1 - m_2\cos\gamma)\,q_3 + (m_1 - m_2\cos\gamma)\,\ddot{q}_4 + m_1\ddot{q}_5 - m_3\cos\gamma\,\ddot{q}_6 + K_2q_2 = 0 \quad (27)$$

$$(m_1 - m_2\cos\gamma)\,\ddot{q}_1 + (m_1 - m_2\cos\gamma)\,\ddot{q}_2 + (m_1 - 2m_2\cos\gamma + m_5)\,\ddot{q}_3 + (m_1 - 2m_2\cos\gamma + m_5)\,\ddot{q}_4 + (m_1 - m_2\cos\gamma)\,\ddot{q}_5 + (m_4 - m_3\cos\gamma)\,\ddot{q}_6 + K_3q_3 = 0 \quad (28)$$

$$(m_1 - m_2\cos\gamma)\,\ddot{q}_1 + (m_1 - m_2\cos\gamma)\,\ddot{q}_2 + (m_1 - 2m_2\cos\gamma + m_5)\,\ddot{q}_3 + (m_1 - 2m_2\cos\gamma + m_5)\,\ddot{q}_4 + (m_1 - m_2\cos\gamma)\,\ddot{q}_5 + (m_4 - m_3\cos\gamma)\,\ddot{q}_6 + K_4q_4 = 0 \quad (29)$$

$$m_1\ddot{q}_1 + m_1\ddot{q}_2 + (m_1 - m_2\cos\gamma)\,\ddot{q}_3 + (m_1 - m_2\cos\gamma)\,\ddot{q}_4 + m_1\ddot{q}_5 - m_3\cos\gamma\,\ddot{q}_6 + K_5q_5 = 0 \quad (30)$$

$$-m_3\cos\gamma\,\ddot{q}_1 - m_3\cos\gamma\,\ddot{q}_2 + (m_4 - m_3\cos\gamma)\,\ddot{q}_3 + (m_4 - m_3\cos\gamma)\,\ddot{q}_4 - m_3\cos\gamma\,\ddot{q}_5 + m_6\ddot{q}_6 + K_6q_6 = 0 \quad (31)$$

Let

$$q_r = A_r e^{i\omega t} \quad (32)$$

Differentiating Eq. (32) twice:

$$\ddot{q}_r = -\omega^2 A_r e^{i\omega t} \quad (33)$$

Substituting $\omega^2 A_r = N_r$, Eq. (33) may be written:

$$\ddot{q}_r = -N_r e^{i\omega t} \quad (34)$$

Substituting Eqs. (32) and (34), the six frequency Eqs. (26) to (31) are written in matrix form (see Matrix 1), which can be solved by iteration method, yielding the lowest frequency of the equivalent vibrating system as shown in Figure 1.

To find the next lowest frequency of the equivalent vibrating system, the orthogonality relation for the principal modes may be utilized:

$$\sum_{i=1}^{n}\sum_{j=1}^{n} m_{ij}A_i^{(r)}A_j^{(s)} = 0 \quad (35)$$

where $A_i^{(r)}$ and $A_j^{(s)}$ are the coefficients of two normal modes of oscillation. Substituting the proper values for m_{ij} and $A_i^{(r)}$ from Matrix 1 solved by iteration method, Eq. (35) may be written:

$$\begin{bmatrix} \frac{m_1}{K_1} \\ \frac{m_1}{K_2} \\ \frac{m_1-m_2\cos\gamma}{K_3} \\ \frac{m_1-m_2\cos\gamma}{K_4} \\ \frac{m_1}{K_5} \\ -\frac{m_3\cos\gamma}{K_6} \end{bmatrix} N_1A_1 + \begin{bmatrix} \frac{m_1}{K_1} \\ \frac{m_1}{K_2} \\ \frac{m_1-m_2\cos\gamma}{K_3} \\ \frac{m_1-m_2\cos\gamma}{K_4} \\ \frac{m_1}{K_5} \\ -\frac{m_3\cos\gamma}{K_6} \end{bmatrix} N_2A_2 + \begin{bmatrix} \frac{m_1-m_2\cos\gamma}{K_1} \\ \frac{m_1-m_2\cos\gamma}{K_2} \\ \frac{m_1-2m_2\cos\gamma+m_5}{K_3} \\ \frac{m_1-2m_2\cos\gamma+m_5}{K_4} \\ \frac{m_1-m_2\cos\gamma}{K_5} \\ \frac{m_4-m_3\cos\gamma}{K_6} \end{bmatrix} N_3A_3 + \begin{bmatrix} \frac{m_1-m_2\cos\gamma}{K_1} \\ \frac{m_1-m_2\cos\gamma}{K_2} \\ \frac{m_1-2m_2\cos\gamma+m_5}{K_3} \\ \frac{m_1-2m_2\cos\gamma+m_5}{K_4} \\ \frac{m_1-m_2\cos\gamma}{K_5} \\ \frac{m_4-m_3\cos\gamma}{K_6} \end{bmatrix} N_4A_4 + \begin{bmatrix} \frac{m_1}{K_1} \\ \frac{m_1}{K_2} \\ \frac{m_1-m_2\cos\gamma}{K_3} \\ \frac{m_1-m_2\cos\gamma}{K_4} \\ \frac{m_1}{K_5} \\ -\frac{m_3\cos\gamma}{K_6} \end{bmatrix} N_5A_5 + \begin{bmatrix} -\frac{m_3\cos\gamma}{K_1} \\ -\frac{m_3\cos\gamma}{K_2} \\ \frac{m_4-m_3\cos\gamma}{K_3} \\ \frac{m_4-m_3\cos\gamma}{K_4} \\ -\frac{m_3\cos\gamma}{K_5} \\ \frac{m_6}{K_6} \end{bmatrix} N_6A_6 = 0 \quad (36)$$

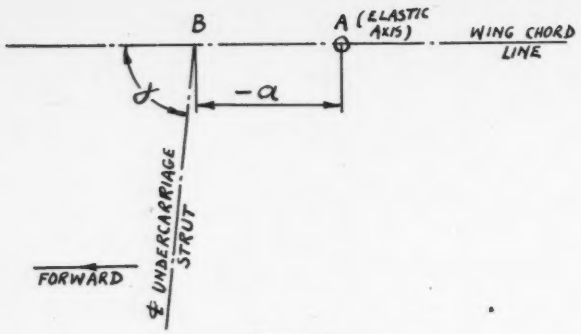

Figure 4

$A_1, A_2, A_3, A_4, A_5, A_6$, is a new set of values representing a solution of the oscillation problem, in which the principal mode corresponding to the lowest frequency as calculated from Matrix 1 is not present. From Eq. (36), A_6 may be calculated and substituted in Eqs. (26) to (31). These five frequency equations can be written in matrix form and solved by iteration method, yielding the next lowest frequency of the equivalent vibrating system. Using the method described above all natural frequencies can be found. However, for engineering purposes, the lowest natural frequencies (usually the fundamental and first) are sufficient.

If the undercarriage strut is fixed forward of the elastic axis of the wing, Matrix 1 can be used but the distance a has to be taken with minus sign and the angle γ between chord line and undercarriage strut should be measured as shown in Figure 4.

Case 2—The undercarriage strut is fixed to the rib which is a cantilever beam built into the structural box of the wing.

In calculating the components of the velocity v_{zn} and v_{xn} for the concentrated masses of the undercarriage strut in the mode q_5, Eqs. (7) and (9) may be used as an approximation. In Eq. (9), a has to be replaced by s, which is the active length of the rib considered as cantilever. This approximation is made in order to avoid complication in the solution of the frequency equations. The actual slope at point B is greater than that taken into account assuming the rotation of point B about the fixity (see Figure 5).

Since the rib has a much higher natural frequency than the wing or the undercarriage strut, this approximation should have a negligible influence on the frequencies and amplitudes of the equivalent vibrating system.

Referring to Figures 2 and 5, the velocity of a concentrated mass $\frac{w_n}{g}$ of the undercarriage strut along X axis may be written:

$$V_{nx} = -(\dot{q}_1 + \dot{q}_2)\cos\gamma + (\dot{q}_4 + \dot{q}_3)\left(\frac{z_n}{a} - \cos\gamma\right) + \dot{q}_5\left(\frac{z_n}{s} - \cos\gamma\right) + \eta_n\dot{q}_6 = -(\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5)\cos\gamma + (\dot{q}_3 + \dot{q}_4)\frac{z_n}{a} + \dot{q}_5\frac{z_n}{s} + \eta_n\dot{q}_6 \quad (37)$$

The velocity along Z axis is given by Eq. (13). The kinetic energy T of the entire undercarriage may be expressed as in Case 1:

$$T = \frac{m_1}{2}(\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5)^2 -$$
$$m_2\cos\gamma\,(\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5)(\dot{q}_3 + \dot{q}_4) -$$
$$m_7\cos\gamma\,(\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5)\dot{q}_5 -$$
$$m_3\cos\gamma\,(\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 + \dot{q}_5)\dot{q}_6 +$$
$$m_8(\dot{q}_3 + \dot{q}_4)\dot{q}_5 + m_4(\dot{q}_3 + \dot{q}_4)\dot{q}_6 + m_9\dot{q}_5\dot{q}_6 +$$
$$\frac{m_5}{2}(\dot{q}_3 + \dot{q}_4)^2 + \frac{m_{10}}{2}\dot{q}_5^2 + \frac{m_6}{2}\dot{q}_6^2$$

where:

$$\frac{1}{sg}\sum_{n=1}^{n} w_n z_n = m_7 \quad (38)$$

$$\frac{1}{asg}\sum_{n=1}^{n} w_n z_n^2 = m_8 \quad (39)$$

$$\frac{1}{sg}\sum_{n=1}^{n} w_n \eta_n z_n = m_9 \quad (40)$$

$$\frac{1}{s^2 g}\sum_{n=1}^{n} w_n z_n^2 = m_{10} \quad (41)$$

$m_1, m_2, m_3, m_4, m_5, m_6$ are given by Eqs. (18) to (23) respectively. The potential energy of the system is given by Eq. (25). Applying Lagrange's equations of motion and making the same substitutions as in Case 1, six frequency equations may be written in matrix form (see Matrix 2), which can be solved by iteration method yielding the lowest frequency of the equivalent vibrating system. To find the next lowest frequency the orthogonality relation for the principal modes may be utilized as described in Case 1.

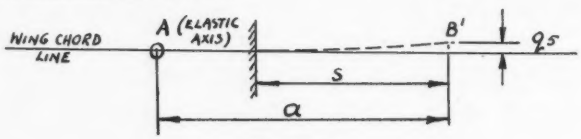

Figure 5

For the undercarriage strut fixed forward of the elastic axis of the wing Matrix 2 can be used, but the distances a and s have to be taken with minus signs, and the angle γ between chord line and undercarriage strut should be measured as shown in Figure 4.

If it is assumed that: $m_7 = m_8 = m_9 = m_{10} = 0$, then Matrix 2 is reduced to Matrix 1, as it is expected.

CALCULATION OF THE GENERALIZED FORCES AT THE LANDING GEAR AXLE OR BOGIE PIVOT FOR THE PRINCIPAL FREQUENCY OF THE SYSTEM

The ground reactions at the axle or bogie pivot can be derived considering the aircraft as a rigid body (see Reference 7). The vertical component of ground reaction and drag load (if a case with drag load is considered) can be resolved along the undercarriage strut and normal to it, as shown in Figure 6, and plotted against time. The generalized forces acting at the axle or bogie pivot along and normal to the undercarriage strut, $F_{Gz}(t)$ $F_{Gx}(t)$ respectively, can be calculated for the equivalent

MATRIX 2

$$\begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \end{bmatrix} = \begin{bmatrix} \frac{m_1}{K_1} & \frac{m_1}{K_1} & \frac{m_1 - m_2\cos\gamma}{K_1} & \frac{m_1 - m_2\cos\gamma}{K_1} & \frac{m_1 - m_7\cos\gamma}{K_1} & -\frac{m_3\cos\gamma}{K_1} \\ \frac{m_1}{K_2} & \frac{m_1}{K_2} & \frac{m_1 - m_2\cos\gamma}{K_2} & \frac{m_1 - m_2\cos\gamma}{K_2} & \frac{m_1 - m_7\cos\gamma}{K_2} & -\frac{m_3\cos\gamma}{K_2} \\ \frac{m_1 - m_2\cos\gamma}{K_3} & \frac{m_1 - m_2\cos\gamma}{K_3} & \frac{m_1 - 2m_2\cos\gamma + m_5}{K_3} & \frac{m_1 - 2m_2\cos\gamma + m_5}{K_3} & \frac{m_1 - (m_2 + m_7)\cos\gamma + m_8}{K_3} & \frac{m_4 - m_3\cos\gamma}{K_3} \\ \frac{m_1 - m_2\cos\gamma}{K_4} & \frac{m_1 - m_2\cos\gamma}{K_4} & \frac{m_1 - 2m_2\cos\gamma + m_5}{K_4} & \frac{m_1 - 2m_2\cos\gamma + m_5}{K_4} & \frac{m_1 - (m_2 + m_7)\cos\gamma + m_8}{K_4} & \frac{m_4 - m_3\cos\gamma}{K_4} \\ \frac{m_1 - m_7\cos\gamma}{K_5} & \frac{m_1 - m_7\cos\gamma}{K_5} & \frac{m_1 - (m_2 + m_7)\cos\gamma + m_8}{K_5} & \frac{m_1 + (m_2 + m_7)\cos\gamma + m_8}{K_5} & \frac{m_1 - 2m_7\cos\gamma + m_{10}}{K_5} & \frac{m_9 - m_3\cos\gamma}{K_5} \\ -\frac{m_3\cos\gamma}{K_6} & -\frac{m_3\cos\gamma}{K_6} & \frac{m_4 - m_3\cos\gamma}{K_6} & \frac{m_4 - m_3\cos\gamma}{K_6} & \frac{m_9 - m_3\cos\gamma}{K_6} & \frac{m_6}{K_6} \end{bmatrix} \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \end{bmatrix} = \frac{1}{\omega^2} \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \end{bmatrix}$$

vibrating system of the wing rib and strut from the principle of virtual work, i.e. the work produced when the components of the ground reaction $F_z(t)$ and $F_x(t)$ are allowed to move through displacements corresponding to six uncoupled modes q_r for one of the principal frequencies of the system (for engineering purposes only the lowest frequencies first and second need to be considered).

Case 1—The undercarriage strut is fixed to the rib which is built-in at each end.

For this case the solution of Matrix 1 gives the values of N_r's which are proportional to q_r's:

$$q_r = \frac{N_r}{\omega^2} e^{i\omega t} \tag{42}$$

The displacement of the axle or bogie pivot along and normal to the undercarriage strut, L_z and L_x respectively, may be obtained by the integration of Eqs. (13) and (14):

$$L_z = (q_1 + q_2 + q_3 + q_4 + q_5)\sin\gamma \tag{43}$$

$$L_x = -(q_1 + q_2 + q_3 + q_4 + q_5)\cos\gamma + (q_3 + q_4)\frac{l}{a} + q_6 \tag{44}$$

since $z_n = l$ and $\eta q_6 = q_6$ at the axle.

Substituting Eq. (42) in Eqs. (43) and (44):

$$L_z = \frac{e^{i\omega t}}{\omega^2}(N_1 + N_2 + N_3 + N_4 + N_5)\sin\gamma \tag{45}$$

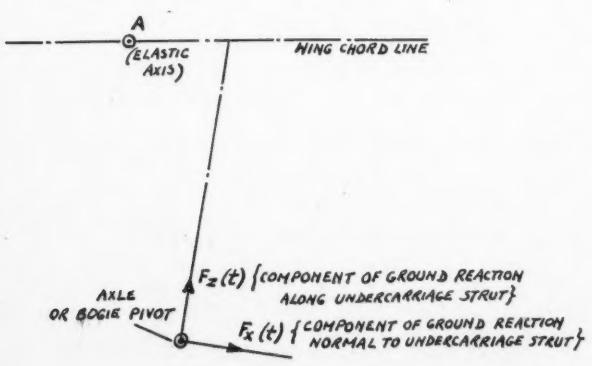
A
(ELASTIC AXIS)
WING CHORD LINE
AXLE OR BOGIE PIVOT
$F_z(t)$ {COMPONENT OF GROUND REACTION ALONG UNDERCARRIAGE STRUT}
$F_x(t)$ {COMPONENT OF GROUND REACTION NORMAL TO UNDERCARRIAGE STRUT}

Figure 6

$$L_x = \frac{e^{i\omega t}}{\omega^2}\left[-\cos\gamma\,(N_1 + N_2 + N_3 + N_4 + N_5) + (N_3 + N_4)\frac{l}{a} + N_6\right] \tag{46}$$

Assuming that the component of ground reaction $F_z(t)$ is allowed to move unity $L_z = 1$, then the component of ground reaction $F_x(t)$ will move normal to the undercarriage strut:

$$\frac{L_x}{L_z} = -\cot\gamma + \frac{\frac{l}{a}(N_3 + N_4) + N_6}{(N_1 + N_2 + N_3 + N_4 + N_5)\sin\gamma}$$

The virtual work W_z done by the components of ground reaction, $F_z(t)$ and $F_x(t)$, when $F_z(t)$ is allowed to move unity:

$$W_z = F_z(t) \times 1 + F_x(t)\left[-\cot\gamma + \frac{\frac{l}{a}(N_3 + N_4) + N_6}{(N_1 + N_2 + N_3 + N_4 + N_5)\sin\gamma}\right]$$

The generalized force $F_{Gz}(t)$ acting at the axle or bogie pivot along the undercarriage strut:

$$F_{Gz}(t) = \frac{W_z}{1} = F_z(t) + F_x(t)\left[-\cot\gamma + \frac{\frac{l}{a}(N_3 + N_4) + N_6}{(N_1 + N_2 + N_3 + N_4 + N_5)\sin\gamma}\right] \tag{47}$$

Assuming that the component of ground reaction $F_x(t)$ is allowed to move unity $L_x = 1$, then the component of ground reaction $F_z(t)$ will move along the undercarriage strut:

$$\frac{L_z}{L_x} = \frac{(N_1 + N_2 + N_3 + N_4 + N_5)\sin\gamma}{-(N_1 + N_2 + N_3 + N_4 + N_5)\cos\gamma + (N_3 + N_4)\frac{l}{a} + N_6}$$

From the virtual work W_x done by the components of ground reactions $F_x(t)$ and $F_z(t)$, when $F_x(t)$ is allowed to move unity, the generalized force $F_{Gx}(t)$ acting at the axle or bogie pivot normal to the undercarriage strut:

$$F_{Gx}(t) = \frac{W_x}{1} = F_x(t) + \frac{F_z(t)\,(N_1 + N_2 + N_3 + N_4 + N_5)\sin\gamma}{-(N_1 + N_2 + N_3 + N_4 + N_5)\cos\gamma + \frac{l}{a}(N_3 + N_4) + N_6} \tag{48}$$

For an undercarriage strut which is mounted forward of the elastic axis of the wing the distance a has to be taken with minus sign in Matrix 1 and in Eqs. (47) and (48).

Case 2–The undercarriage strut is fixed to the rib which is a cantilever beam built into the structural box of the wing.

In Case 2, N_r's are derived by the solution of Matrix 2 and the displacements of the axle or bogie pivot by the integration of Eqs. (13) and (37). Considering again the virtual work of the components of ground reaction as in Case 1, the generalized forces $F_{Gz}(t)$ and $F_{Gx}(t)$ may be expressed respectively:

$$F_{Gz}(t) = F_z(t) + F_x(t)\left[-\cot\gamma + \frac{(N_3 + N_4)\frac{l}{a} + N_5\frac{l}{s} + N_6}{(N_1 + N_2 + N_3 + N_4 + N_5)\sin\gamma}\right] \tag{49}$$

$$F_{Gx}(t) = F_x(t) + \frac{F_z(t)\,(N_1 + N_2 + N_3 + N_4 + N_5)\sin\gamma}{-(N_1 + N_2 + N_3 + N_4 + N_5)\cos\gamma + (N_3 + N_4)\frac{l}{a} + N_5\frac{l}{s} + N_6} \tag{50}$$

The same applies in this case as in Case 1. If the undercarriage is mounted forward of the elastic axis of the wing the distances a and s have to be taken with minus signs in Matrix 2 and in Eqs. (49) and (50).

CALCULATION OF THE RESPONSES AND DYNAMIC LANDING LOADS AT THE LANDING GEAR AXLE OR BOGIE PIVOT

The generalized forces derived for the rigid aircraft are now considered as forcing functions acting on the equivalent vibrating system of the wing rib and undercarriage strut, which vibrates with one of the principal frequencies ω found by the solution of the frequency equations given in matrix form (Matrices 1 and 2). In order to have non-dimensional forcing functions the generalized forces may be expressed:

$$F_{Gz}(t) = A_z f(t) \tag{51}$$

$$F_{Gx}(t) = A_x f(t) \tag{52}$$

where:

$$A_z = \frac{F_{Gz}(t)}{[F_{Gz}(t)]_{max.}} \tag{53}$$

$$A_x = \frac{F_{Gx}(t)}{[F_{Gx}(t)]_{max.}} \tag{54}$$

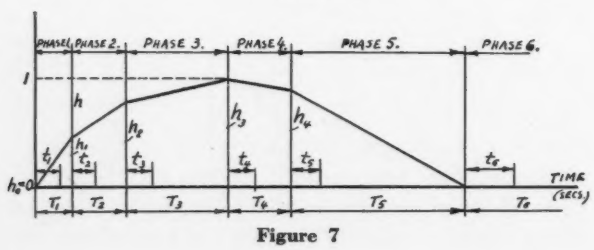

Figure 7

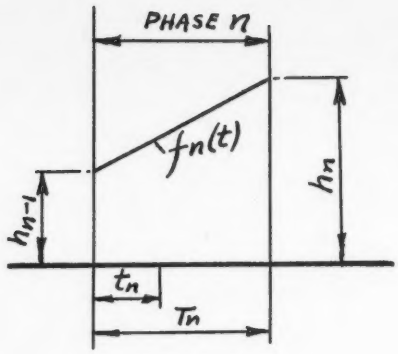

Figure 8

To simplify the calculation of the responses the non-dimensional forcing functions can be approximated by straight lines as shown in Figure 7.

Considering the forcing function $A_z f(t)$ and neglecting structural and aerodynamic damping, for phase n (see Figure 8) the equation of motion may be written:

$$m_z\ddot{z}_n + \omega^2 m_z z_n = A_z f(t)$$

$$\therefore \ddot{z}_n + \omega^2 z_n = \frac{A_z}{m_z} f(t) \tag{55}$$

where m_z is the generalized mass of the entire undercarriage at the axle or bogie pivot along the undercarriage strut and ω is one of the principal frequencies of the system.

From Figure 8:

$$f_n(t) = h_{n-1} + (h_n - h_{n-1})\frac{t_n}{T_n} \tag{56}$$

and the first derivative of Eq. (56):

$$f_n'(t) = \frac{h_n - h_{n-1}}{T_n} \tag{57}$$

The initial conditions for Eq. (55) are:

when $t_n = 0,\ z_n = z_{n-1},\ \dot{z}_n = \dot{z}_{n-1}$

Using Laplace's transforms, Eq. (55) may be written:

$$p^2 f(p) - z_{n-1}\,p - \dot{z}_{n-1} + \omega^2 f(p) = \frac{A_z}{m_z}\left(\frac{h_{n-1}}{p} + \frac{h_n - h_{n-1}}{T_n}\frac{1}{p^2}\right)$$

$$\therefore f(p) = \frac{A_z}{m_z}\left[h_{n-1}\frac{1}{p(p^2+\omega^2)} + \frac{h_n - h_{n-1}}{T_n}\frac{1}{p^2(p^2+\omega^2)}\right] + z_{n-1}\frac{p}{p^2+\omega^2} + \dot{z}_{n-1}\frac{1}{p^2+\omega^2} \tag{58}$$

Expressing in partial fractions the following terms of Eq. (58):

$$\frac{1}{p\,(p^2+\omega^2)} = \left(\frac{1}{p} - \frac{p}{p^2+\omega^2}\right)\frac{1}{\omega^2} \tag{59}$$

$$\frac{1}{p^2\,(p^2+\omega^2)} = \left(\frac{1}{p^2} - \frac{1}{p^2+\omega^2}\right)\frac{1}{\omega^2} \tag{60}$$

Substituting Eqs. (59) and (60) in Eq. (58) and calculating inverse Laplace's transform:

$$z_n = \frac{A_z}{m_z\omega^2}\left\{f_n(t_n) - \left[h_{n-1} - \frac{z_{n-1}}{A_z/m_z\omega^2}\right]\cos\omega t_n - \left[f_n'(t_n) - \frac{\dot{z}_{n-1}}{A_z/m_z\omega^2}\right]\frac{1}{\omega}\sin\omega t_n\right\} \quad (61)$$

$$Response = u_z = \frac{Dynamic\ Displacement}{Static\ Displacement}:$$

$$u_z = \frac{z_n}{A_z/m_z\omega^2} = f_n(t_n) - \left(h_{n-1} - \frac{z_{n-1}}{A_z/m_z\omega^2}\right)\cos\omega t_n - \left[f_n'(t_n) - \frac{\dot{z}_{n-1}}{A_z/m_z\omega^2}\right]\frac{1}{\omega}\sin\omega t_n \quad (62)$$

Using the above formula the computation of the responses may be arranged in the form shown in Table 2.

TABLE 2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PHASE	t_n	T_n	t	$f_n(t_n)$	$f_n'(t_n)$	$\left(\frac{z_n}{A_z/m_z\omega^2}\right)_{G.F.}$	$\frac{z_n}{A_z/m_z\omega^2}$	$\left(\frac{\dot{z}_n}{A_z/m_z\omega^2}\right)_{G.F.}$	$\frac{\dot{z}_n}{A_z/m_z\omega^2}$
1									
2									
3									

t_n in column (2) for each phase starts from zero, and at the end of the n^{th} phase $t_n = T_n$ which is given in column (3). t in column (4) is the time measured from the moment of touch down. Columns (5) and (6) give forcing functions and their derivatives respectively. The expression in column (7) is written in general form as derived from Eq. (62). For phase 1, $z_{n-1} = \dot{z}_{n-1} = 0$ for $t_1 = 0$, and h_{n-1} may be also equal to zero, or to have a value of say h_o, and Eq. (62) may be written:

(a) for $h_{n-1} = 0$,

$$u_{z1} = \left(\frac{z_1}{A_z/m_z\omega^2}\right)_{G.F.} = f_1(t_1) - f_1'(t_1)\frac{1}{\omega}\sin\omega t_1 \quad (63)$$

(b) for $h_{n-1} = h_o$,

$$u_{z1} = \left(\frac{z_1}{A_z/m_z\omega^2}\right)_{G.F.} = f_1(t_1) - h_o\cos\omega t_1 - f_1'(t_1)\frac{1}{\omega}\sin\omega t_1 \quad (64)$$

Column (8) gives numerical values of column (7), which for phase 1 can be derived from one of the formulae Eqs. (63) or (64); therefore the responses for all phases can be calculated without knowledge of the numerical value of the generalized mass m_z. Column (9) is derived by differentiation of column (7). Column (10) gives the numerical value of column (9).

Having the response u_z, u_x can be calculated in the same fashion, and then the dynamic landing loads at the landing gear axle or bogie pivot for the elastic aircraft are:

(1) along the undercarriage strut, $u_zA_zf(t)$,

(2) normal to the undercarriage strut, $u_xA_xf(t)$.

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ELECTRONIC DATA PROCESSING IN AIR TRANSPORT

by L. Richardson*

Trans-Canada Air Lines

When scheduled air transportation first began, the operational problems encountered were few in number, mainly because there were few of the ingredients required – passengers, airports and airplanes. Public demand for better and faster transportation and the ability of the aircraft producer to comply kept the interest level high at all times, which probably partially accounts for the phenomenal rate of growth in this part of the transportation industry. We are now entering the era of the big jets, which will make even the furthest destination only a few hours away, and there is still no indication of shortage of demand for air travel.

Shortages are being felt, however, mainly by the airline operator. They are rapidly becoming in short supply of some even more important ingredients than those previously mentioned. These are air space, terminal facilities and "time". The airways are already so crowded that safety separation is being prejudiced from control facilities that are becoming hopelessly inadequate; terminal facilities are bulging at the seams with the great onflux of passengers, and "time", well there just isn't enough of it left for the great quantity of tasks that everyone knows ought to be done, to be completed without compromise.

Electronic data processing promises some relief from some of these burdens. Modern methods of analysis that have been developed to assure the most effective use of electronic computers, are serving as valuable aids in the realization of improved operating procedures and techniques. An aircraft flying on an airway at several thousand feet actually is the end product of a very considerable amount of analysis and planning by numerous teams of personnel who have, in the process, manipulated huge quantities of data. This then is one of the areas where the processessing of data at electronic speeds pays high dividends.

THE INTEGRATED OUTLOOK

The basic purpose of any organization engaged in the business of air transportation is to provide for the carriage of passengers and goods between all points in its operating network. This must be done in a manner that is consistent with the maintenance of a sound economic position and good standards of service at the lowest possible cost to the user. These over-all criteria can only be achieved if each functional area within the airline structure is performing in a harmonious relationship with every other functional area. A measurement of effectiveness based upon data processing principles and called a flow diagram can be constructed for the airlines as a whole, in order to best assess which areas are the most susceptible to mechanization and to what extent this process should be carried out. Such a plan, when used with real information, also isolates expensive duplication of data and assures protection against it in any future system.

APPLICATION OF COMPUTERS

The view of an airline as seen by a systems engineer is, in the main, one of so many points of operation, so many aircraft, their loading, the rate of generation of information and the amount of control required to effectively realize the established operational criteria. He is likely to segregate this information according to its use; if it pertains to the daily operating routine it is handled in one way while if it is useful for future planning purposes it is handled in another. This segregation generally implies that for operating information the computer must complete a decision making process at the time the event is taking place or before, while on the other hand for planning purposes it is possible to let information accumulate for later processing in bulk form on the same computer. In the first instance, by way of an example, the calculation could be a most economical flight plan and, in the second, a payroll computation.

One specific role for electronic computation that is being considered by several airlines, that is more interesting than that of payroll or the more normal accounting functions, is that of utilizing an electronic digital computer to take over the brainwork of accounting for passenger reservations. Due to the great volume of passenger traffic and the amount of communication involved between the various points of sale and the controlling centre, it is virtually impossible for the human machine to follow the pace. Most air carriers have reached the point of diminishing return in this area and are now searching for a real and lasting solution. In Canada, the situation differs little and already, during

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busy periods, airline seats are being operated upon at the rate of more than one per second.

All reservations operations are similar in form, regardless of the airline involved, and are probably the most frequently occuring event in any airline. In roles such as this the computer is in its element. Computers have been built especially to conduct this function while others designed for general use have been programmed to carry out the very same function. As an indication of the rate at which reservations may be handled, a medium speed computer, not specifically designed for reservations use, can be programmed to process passenger reservations at the rate of five per second.

Such an operation can only be useful if an airline sales agent in Vancouver or Halifax, for example, may determine for a passenger from a computer, say in Toronto, whether or not there is a seat, during the time he is in consultation with the passenger. This implies a very extensive communication system which would embrace all points of operation in Canada. Such a system is presently on the drawing boards and includes the detection of errors and accurate completion of any reservation within a small number of seconds. Sales agents would merely actuate a small device similar to a desk adding machine; each message would be automatically transmitted to the computer and the answer displayed in illuminated form on the same device.

USEFUL BY-PRODUCTS

The cost of operating a fleet of modern aircraft is staggering and, therefore, every effort is made to schedule aircraft for as close a match to the demand pattern as possible. In practice, the only real information known is in terms of service rendered, rather than service requested. Here again is indicated an extremely important role for the computer.

Since one of the main components of a digital computer is a memory system, it is possible, therefore, to reassemble each contact between the public and the airline in terms of the actual demand pattern in order to analyze to what extent the demand is being met. From this information, modifications to existing schedules could be formulated and tried out on the computer before being impressed upon the travelling public.

Operations and analysis of this nature represent an enormous task – much too large to be carried out by teams of clerical workers – so, in practice, simplifying assumptions are applied. Because each contact between a patron and the airline provides a unit of statistical information, regardless of whether or not they were actually satisfied, this indicates a direct functional inter-relationship between the scheduling and reservations structures. Consideration of both these functions simultaneously, in an integrated system similar to that described, is interesting in that it implies that each improvement in the schedule decreases the problem of seat reservations. This is a real solution and while some operators have tackled the reservations problems singularly, experience is indicating that this technique only assists them in accommodating the problem but does not provide a solution. Present thinking is indicating that a slight extension in computing will reap benefits that they cannot afford to be without.

THE FUTURE

In general, any operation which is capable of being precisely defined may be carried out on an electronic computer at a much faster rate than otherwise obtainable. Computers, therefore, find application in areas where there is a small amount of computing required but which occurs at frequent intervals, such as in passenger reservations, and also where there is a large amount of computing which may occur infrequently, such as in statistical analysis etc.

With respect to the actual operation of aircraft and their control, it is conceivable that some of the routine talking that the pilot now must do with ground controlling stations, and for which he has little time, may be taken over by automatic data links. These links would be coupled with computers which would at all times monitor the operation for adherence to routine, while at the same time feeding progress reports to the airlines concerned.

Specialized equipments, such as automatic fare calculators and ticket vendors, passenger check-in machines at airports and a host of other devices too numerous to mention, are already appearing in service or on the horizon. The future does indeed look exciting and inevitably will result in greatly increased operational efficiency. Although the initial cost of this type of equipment runs high, it has in most installations more than paid its own way and in future the travelling public may look forward to the benefits therefrom without the necessity of reaching further into their pocketbooks.

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(a) Typewritten, double-spaced,
(b) On one side of 8½ x 11 white paper,
(c) With wide margins, approximately 1½", and
(d) With pages numbered consecutively.

Manuscripts must be in final form; the addition of material after acceptance by the Institute cannot be permitted.

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(a) Titles should be brief;
(b) The name and initials of the author should be written as he prefers; (Rank or title preceding the name e.g. Wing Commander or Dr., should be included but abbreviations of degrees etc., after the name, should be omitted.);
(c) The name of the organization with which the author is associated should be shown under his name; and
(d) The author's position in the organization, referred to in (c) above, should be shown as a footnote to the first page.

Summaries. Each paper should be preceded by a summary
(a) Of 100 to 300 words, (10 to 35 lines, double-spaced),
(b) In non-specialist language, so far as possible,
(c) Stating the main conclusions of the paper.

Sub-Headngs and Paragraph Numbering. Sub-headings should be inserted by the author at frequent intervals. Paragraphs should not be numbered.

References. References referred to by the author should be treated thus:–
(a) References should be numbered consecutively throughout the paper;
(b) An allusion to a reference should be indicated by a bracketed numeral e.g. "It has been shown by Dr. T. T. James (7) . . . ";
(c) Direct citation of a reference in the text should be written in full, e.g. "As shown in Reference (7) . . . "; and
(d) References should be grouped together in numerical order at the end of the paper, each showing
first, the numerical designation, e.g. "(7)".
second, the author's name, e.g. "James, T. T."
third, the title of his work, e.g. "Aerodynamics and Ballistics"
fourth, the title, volume, issue no, and date identifying the publication in which it appeared, e.g. "R.B.S. Journal, Vol. 7, No. 77, July 1907".

Thus "(7) James, T. T.,–Aerodynamics and Ballistics, R.B.S. Journal, Vol. 7, No. 77, July 1907."

Footnotes. Comments on or amplification of the text should be given in footnotes, appearing at the bottom of the appropriate pages.
(a) Footnotes should be designated alphabetically and consecutively throughout the paper; and
(b) A reference to a footnote in the text should be indicated by a bracketed letter, e.g. "omitting consideration of the third power (c) . . . "

Figures, Tables and Equations. Reference in the text to
(a) Figures and Tables should be given in full, e.g. "Figure 7", but
(b) Equations should be abbreviated to Eq., e.g., "Eq.(7)" or "Eqs.(5) and (6)".

Drawings. Drawings should be
(a) Individually identified by Figure or Table number,
(b) Not larger than 12" x 16",
(c) In black ink on white paper or tracing cloth, and
(d) Capable of being reduced to 3½" wide without loss of legibility of lettering or other detail.

Photographs. Photographs should be
(a) Black and white, glossy prints, and
(b) Individually identified by Figure number, written on a separate piece of paper affixed to the back: writing on the back of the photographs should be avoided.

Captions. Each Figure and Table should be identified by a caption, in addition to its number, e.g., "Figure 12 Theoretical lift distribution".
(a) The caption of a Table should be shown at the top of the Table;
(b) The caption of a Figure should be shown preferably outside the boundary of the Figure; and
(c) A complete list of Figure and Table captions should be given on a separate sheet of the manuscript.

Mathematical work. Only the simplest mathematical expressions should be typewritten; others should be carefully written in ink. Mathematical work should be
(a) Uncrowded–plenty of space should be provided to accommodate directions to the printer–,
(b) Repeated on a separate sheet of the manuscript, again uncrowded and with plenty of space around each expression,
(c) Clearly written to distinguish between like symbols. e.g. between zero and the letter 'o', and between Greek and English letters of similar form, and
(d) Accompanied by a manuscript "index" of the Greek letters used in the paper, identifying each letter by a name, e.g. "α–alpha".

In addition the following practices should be adopted:
(a) Simple fractions appearing in the text should be shown with a solidus, e.g. A/(B+C) rather than as

$$\frac{A}{B+C}$$

(b) Complicated expressions should be identified by some convenient symbol, if necessary to avoid repetition of the whole expression; and
(c) Complicated subscripts and exponents, and dots and bars over letters or symbols should be avoided.

Symbols and Abbreviations. Consistency is important;
(a) The symbols recommended in the American Standards Association "Letter Symbols for Aeronautical Sciences" ASA Y10-7–1954 should be used wherever practicable; and
(b) Abbreviations of units should be shown in lower case without periods, e.g. lb, mph, bhp, etc.

Mailing. Papers should be mailed to The Secretary, Canadian Aeronautical Institute, 607 Commonwealth Building, 77 Metcalfe St., Ottawa 4, Canada.
(a) Drawings and photographs may be mailed rolled or flat, not folded;
(b) Manuscripts should be mailed flat.

C.A.I. LOG

SECRETARY'S LETTER

With one thing and another, the work at Headquarters keeps me pretty well tied down and I find it very difficult to get away for any extended period while the Institute and its Branches are active, that is between August and the following June. Unfortunately January, of all the months of the year, gives me my best chance of a break and this year I again took this opportunity to visit our Branches in the west. So far as the weather is concerned, these January jaunts are pretty bleak but, in contrast, it is a rewarding experience to meet our members and to see something of the Branches on their home grounds.

WINNIPEG

Winnipeg was my first port of call, on the 14th January. There I had an opportunity to discuss with Mr. Eden and Mr. Gross, the Branch Chairman and Secretary respectively, the detail plans for the Mid-season Meeting, which will be held in February. Everything seems to be coming along well; I saw the rooms set aside for us in the Fort Garry Hotel and the accommodation, all more or less self-contained on the 7th floor, should prove to be very good for a meeting of this sort.

After this business session, I had dinner with the Branch Executive and Committee Chairmen. We talked about all manner of things connected with the Institute and I came away with some useful ideas; we could have talked all night.

EDMONTON

Next day I travelled to Edmonton by a leisurely DC-3 which, though it stopped almost everywhere on the way, fitted my timetable admirably. "To one who has been long in the city pent 'tis very sweet to look into the fair and open face of heaven" – and how open it is on a clear day across the snow-covered prairies! However, there was a sharp change of tempo when I reached my destination.

On arrival I was met by Mr. Portlock, the Branch Chairman, and whisked away to the first Annual Dinner of the Branch. In January last year I attended their first meeting and it was, therefore, a very great pleasure to be present on this occasion; I renewed acquaintance with many members and, I am glad to say, I saw many new faces since my last visit. Mr. Saunders of Calgary was there too. The meeting was addressed by Mr. Parkin, Director of the N.A.E., who, like me, had come all the way from Ottawa – but not by DC-3!

It was a most successful affair.

COLD LAKE

The Branch at Cold Lake is perhaps unique in the annals of technical societies. It is part of the life of this isolated civilization in the wilderness.

I was picked up at Edmonton by S/L Christie, the Branch Chairman, and enjoyed the nostalgic experience of sitting up front in a Mitchell for this part of my journey. That evening, I met the members of the Branch and gave them a rather rambling talk about the origin, history and purposes of the Institute. It was a pleasant and informal meeting, which I thoroughly enjoyed, though I feel sure that the others, in their arctic exile, regretted that their Chairman had completed only part of his mission in fetching me (and an oleo leg) from Edmonton; he was supposed to bring a T.C.A. film on Bermuda!

Before I left the next morning, S/L Christie showed me around the Station. I can only say that it is quite a place. An Otter took me back to Edmonton.

CALGARY

I had a five hour stop-over at Calgary on my way from Edmonton to the coast. Mr. Saunders, Vice-Principal of the Provincial Institute of Technology and Art, met me at the airport. Mr. Saunders is the Chairman of our Alberta Committee on Education and Training and we discussed this subject and the curriculum of the Institute (his Institute). He also arranged for me to say a few words to about 60 students in the aeronautical course.

We still have no Branch at Calgary but I think that we shall have one fairly soon.

VANCOUVER

And so on to Vancouver. I arrived in the evening of the Thursday and was met by Mr. McWilliams, the Branch Secretary. Unfortunately the Chairman, Mr. Gray, was leaving for England next day but I had breakfast with him before he left. Mr. McWilliams and I went in the opposite direction and visited the Student Section at the Canadian Services College, Royal Roads, on Vancouver Island. We were met at Victoria by the Student Adviser, F/L Lewis. We had lunch with the Senior Cadet members of the Institute and then attended a Section Meeting under the Chairmanship of Cadet Stedman – and a very good meeting it was. Mr. McWilliams and I said a few words to them. I was very encouraged by all I saw at Royal Roads and, except for the lack of time in their very tight academic timetable, they have all the makings of a successful C.A.I. Student Section.

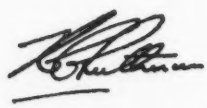
I concluded my tour by attending the Vancouver Branch January Meeting in the evening. Here again I met many old friends and had a chance to chat to a few of them both before and after the formal session. Mr. Brinkman of United Airlines was the speaker of the evening but I will leave it to the Branch Secretary to report on that aspect of the meeting.

CONCLUSION

A T.C.A. Viscount brought me back to Ottawa on the Saturday. In the week I had visited four Branches and Calgary – not to mention the visit to Royal Roads; I had attended three Branch meetings and a Student Section meeting. To me the tour was most valuable and I can report to the Institute at large that I found everything very vigorous and healthy wherever I went. The C.A.I. is doing a good job.

This letter does not give me the scope to mention everybody whom I met and whose hospitality I enjoyed. However, I hope that they will realize that I remember who they were and greatly enjoyed meeting them. I hope that I shall see many of them again in Winnipeg on the 25th/26th February.

Finally, I would say to Halifax that I have not forgotten them. I will wing my way eastward as soon as I can.



McCURDY AWARD

The McCurdy Award will be presented at the Annual General Meeting on the 27th - 28th May, 1957.

It is presented each year

To A Resident of Canada,

For Achievement in design, manufacture or maintenance related to aeronautics.

NOMINATIONS ARE INVITED

Each nomination should include

(a) The name and affiliation of the nominee,

(b) Confirmation that he is a resident of Canada,

(c) A citation of the particular achievement for which the nomination is being put forward, and

(d) The name of the nominator.

The nominee need not be a member of the C.A.I. and the achievement need not have taken place within the last year, though it should be recent.

Nominations should be in the hands of the Secretary not later than the 15th March, on which date they will be handed over to the McCurdy Award Selection Committee.

BRANCHES

NEWS

Vancouver

Student Section November Meeting

Reported by G. R. Engel

Last November, twelve members of the C.A.I. Student Section at Royal Roads, Victoria, were shown through Boeing Aircraft Company's plant in Seattle. Mr. A. Hill, head of Public Relations for Boeing, arranged and conducted the tour.

At this time, Boeing is building B-52 jet bombers in its Seattle plant and the tour was mainly to take a look at the process of this plane's construction. As a background, Mr. Hill gave a brief resume of the Company's history, a picture of the aircraft's development from design to flight and the vast network of sub-contractors who make parts for the aircraft, as well as the complex economic structure which is necessary to support such an operation.

This information was the basis of the tour of the various production levels from the engineers' draughting boards, the machine and sheet metal shops, various sub-assembly sections which build wing sections, fuselage sections and so on to the final assembly area where all the parts and components were merged into the form of the finished B-52.

One could not help but be impressed by what was seen. Little technical detail could be gleaned from a tour of this nature. However, it served as a concrete illustration of the general principles by which the manufacturer operates.

Student Section January Meeting

Reported by A. O. Manson

A meeting of the Royal Roads Student Section of the C.A.I. was held in the Grant Block of Royal Roads on January 12, 1957, at 0800 hours. The Staff Adviser, F/L K. E. Lewis, and fifteen members were present.

The Chairman, Mr. M. W. Stedman, opened the meeting by giving a few general announcements of interest to all members. The Secretary of the C.A.I., Mr. H. C. Luttman, will visit the College on Friday, January 18th, to attend a meeting where Cadets will have the chance of talking to and questioning him on details of the C.A.I. F/L Lewis stated that this would be an excellent opportunity for the Cadet members to enter into discussion with men who are in the same field of work in which they will be following in years to come.

Mr. Stedman then stated that the Secretary had written to Boeing Aircraft in Seattle for a film to be presented at a future meeting and that the results of this correspondence will be forthcoming soon.

An offer has been made to C.A.I. members by Bunhill Publications Ltd. to obtain subscriptions of the monthly magazine, Aircraft Engineering, at a reduced rate. Mr. Stedman distributed a number of order forms for this magazine.

A paper was then presented by Cadet A. G. A. Pearson on the subject of "Propulsion". Cadet Pearson first divided aero-engines into three categories – Reciprocating, Jets and Rockets. He then gave a short history of the development of reciprocating engines. One of them, the Wasp R1340, developed by Pratt & Whitney in 1929, seems to be one of the better types, having survived the ages to become, with a few modifications, the engine still in use with the well-known plane, the Harvard. Cadet Pearson then went on to describe the various types of jet engines, ending his informative talk with a description of the famous German V1 and V2 rockets used against Great Britain during World War II.

The lecture was followed by the film "Powered Flight". This was a documentary film on the history of flight from the earliest pioneers to the present.

The meeting was moved adjourned by Cadet Engel and seconded by Cadet G. G. Hopp. At 0950 hours, the Chairman, Mr. Stedman, adjourned the meeting.

Cold Lake–Reported by R. W. Ellard

November Meeting

The sixth meeting of the Cold Lake Branch of the C.A.I. took place in the Library of the Sergeants Mess on Monday, November 19th, at 8 p.m.

The meeting was opened by the Branch Chairman, S/L R. G. Christie, who gave a report on the Branch activities, including a meeting of members interested in the Provincial Education Committee.

He introduced the speakers from Trans-Canada Air Lines, Mr. A. Bergum of the Sales Dept., Edmonton, and Mr. J. J. Eden, Senior Engineer Mechanical Systems, from Winnipeg.

Mr. Bergum showed a film entitled "No Barriers", which lasted for approximately one-half hour and depicted the growth of transportation in Canada from Jacques Cartier to the present airline network.

Mr. Eden then spoke on "An Operator's Introduction to the Jet Age".

He reviewed the operational performance of the Viscount powerplant to date, comparing its performance with that of other powerplants in the TCA fleet on the basis of featherings, unscheduled removals, delays and costs. He indicated the possible developments and improvements which could be made as a result of this review and concluded that the gas turbine had not only quickly established itself in civil airline use but was already out-performing piston engines used by the same operator while still maintaining a compatible level of cost. He commented that the gas turbine was a new means of propulsion and should be treated in this manner. In an attempt to peep into the future, he specified some possible requirements and looked forward to the time when jet propulsion would afford three-dimensional controlled transportation.

A brisk question period ensued and the meeting closed at 11 p.m. Thirty-two members attended this meeting.

December Meeting

The seventh meeting of the Cold Lake Branch of the C.A.I. took place in the Library of the Sergeants Mess at 8 p.m. on Tuesday, December 11th.

The Chairman, S/L Christie, opened the meeting with a discussion of the Branch business and was followed by Mr. D. L. Wallis who gave a report on the joint C.A.I./I.A.S. meeting in Toronto.

W/C R. D. H. Ellis, Chairman of the Programme Committee, introduced the speaker, Mr. H. D. Procter-Gregg of Avro Aircraft Ltd., a member of the local Branch. The title of Mr. Procter-Gregg's paper was "Some Modern Approaches to Drag Reduction".

He introduced his talk by deploring the use of coined names in a technical paper without proper definition and stated that his paper was written in an attempt to clear up some of these names in the drag field.

He pointed out that we were now fast approaching the era of powered flight and leaving that of the powered glider.

The speaker carefully defined drag, the non-dimensional coefficients and symbols to be used in the paper, and then introduced the "drag family" show-

Montreal Branch 1956-57 Executive. Standing (l to r) H. H. Whiteman (Notices Committee Chairman), G. C. Keefer (Program Committee Chairman), H. A. Reid (Treasurer), T. A. Harvie (Chairman), E. B. Schaefer (Councillor and Vice-President of the C.A.I.), J. W. J. Truran (Attendance Committee Chairman), C. G. MacLeod (Arrangements Committee Chairman). Kneeling (l to r) W. B. Boggs (Membership Committee Chairman), C. R. Thompson (Secretary), H. A. Ross (Vice-Chairman). Absent: R. J. Conrath (Councillor).

Head Table — Montreal Branch January Meeting. (l to r) H. A. Reid, A/V/M A. L. James, B. J. Kaganov, T. A. Harvie, E. B. Schaefer, Col. P. Larson, G. C. Keefer.

ing how each form of drag was paramount in one section of the speed range. Drag reduction was not necessarily a good thing since there exists a speed for minimum drag below which an aircraft becomes unstable. In describing the boundary layer in both viscous and non-viscous flow, he showed how the introduction of turbulence could reduce the wake drag and even the total drag in the presence of large pressure gradients. This was illustrated by the use of vortex generators in many new high altitude aircraft, such as the V-bombers in England.

The blown flap was discussed as an example of reattaching a separated flow and reducing the wake drag.

Transonic and supersonic drags were examined, mainly with regard to planform, and it was shown that when Mach 2 was approached, the low aspect, unswept, tapered wing was probably superior to other types from the drag point of view. The area rule was described and its very powerful effect on the transonic region was shown, although it was also pointed out that its use was limited to below Mach 1.5.

In conclusion, Mr. Procter-Gregg looked into the future and in describing the jet flap indicated the tremendous changes that could be expected from its use if a three-dimensional model could be produced.

A general discussion followed, refreshments were served and the meeting ended at 11 p.m. Twenty-eight members attended this meeting.

Montreal–

Reported by W/C C. R. Thompson

January Meeting

An introduction to automatic electronic computing for engineering calculations was the topic of the talk to the January 1957 meeting of the Montreal Branch of the Canadian Aeronautical Institute.

The speaker was introduced by the Chairman, Mr. T. A. Harvie, who pointed out that Mr. B. J. Kaganov had a wide background of practical experience on which to base his talk. The text of the talk will be submitted to the Publications Committee and we hope that it will be published in the Journal in due course.

Questions afterward brought out the information that the IBM equipment discussed was capable of solving a 92x92 matrix and that the accuracy was of the order of 99.99%. One question on how much money was actually saved by this equipment brought the reply that introduction of the equipment never lowered the budget for an engineering department but it certainly allowed them to tackle and solve problems which they could not do without the equipment.

The speaker was thanked by Mr. F. W. M. Moore, who stated that all present appreciated the talk which brought out the limitations and accuracy of the equipment, the new type of thinking which it required and the value of the equipment as long as it was used on the right type of problem.

Toronto–Reported by W. T. Heaslip

January Meeting

The regular January meeting of the Toronto Branch was held on Thursday, January 17th, with the Vice-Chairman, Mr. J. W. Ames, presiding. W/C E. P. Bridgland opened the meeting by presenting a resume of the programs for the remainder of the season. He then carried on to introduce the speaker, Mr. V. E. Crompton, Assistant to the Vice-President of Sales and Service, Orenda Engines Ltd.

In introducing his subject, "The Philosophy of Gas Turbine Aero Engine Development", the speaker noted that economical aircraft operation required versatility of performance with respect to operating altitudes, speeds and ranges and that this was basically a function of engine performance. The lack of a single gas turbine powerplant to cover the whole sphere is graphically illustrated in complementary roles played by the turboprop in the short-medium range and the straight jet in the long distance fields.

The speaker elaborated on these basic engine types, pointing out the limitations of the turboprop at high speeds. He noted, however, that current developments would permit high speed (up to possibly Mach 2.5) but at the price of lower propulsive efficiency and with a much increased noise level. In discussing the turbojet, it was pointed out that the chief gain was to be made with higher compression ratios which lead to lower specifics. Generally, this is accomplished by the use of twin spool compressors, though some companies feel this problem can be adequately handled with single shaft engines. These designs, however, present problems in rapid surge free acceleration leading to serious complications in detail design. The twin spool design philosophy, which is followed at Orenda Engines Ltd. in providing independent H.P. and L.P. sections which run at their optimum speeds, permits very high compression ratios but avoids the surging problem which is

especially critical at high altitude supersonic flight.

In discussing the by-pass engine, Mr. Crompton showed that the greater propulsive efficiency achieved by this engine represented significant increases in payload and/or range over that achieved with normal turbojets in transport applications. He also stated that he felt the engine had supersonic applications, as he saw no reason why the large portion of unburned air could not be utilized in ramjet action at speeds in excess of Mach 1.7.

The question of engine selection for a supersonic airliner was considered at some length and it was pointed out that the criteria of a good engine is the minimum weight of engine plus fuel for a given operational requirement. In-flight conditions are all-important in this analysis, as there is an optimum pressure ratio for maximum thrust for each flight condition. Aircraft forward speed is a major parameter, as higher speeds increase inlet temperatures and produce corresponding changes in compressor delivery temperatures, which, when considered with limiting turbine temperatures, controls the amount of energy that can be introduced by fuel. Such an analysis leads to a requirement for lower compressor pressure ratios than would be expected for flights at lower speeds.

On the question of engine size, Mr. Crompton pointed out the advantage of large engines inasmuch as they presented less frontal area than a number of smaller engines of the same total thrust. Even on buried installations, the multiplicity of small engines suffered because of disruption to the wing structure if they could be accommodated at all and because the intake or jet pipe length to diameter ratios became large. He also noted that the cost of the installation favoured the large engine rather than a group of smaller units.

In his closing remarks, the speaker touched on fuel consumption figures and sounded a warning that many of the advertised figures showing high thrusts and low specifics are incompatible. Both numbers may be possibles for the engine but they may not occur together.

The speaker was thanked by Mr. R. B. McIntyre, who, after extending his appreciation for a most excellent lecture, noted that it was very refreshing to hear from a salesman who was so well qualified technically and who, in this lecture and in his normal business duties, set forth the facts and avoided partial truths and evasive statements.

Edmonton—Reported by H. E. Davenport

January Meeting

The first Dinner Meeting of the Edmonton Branch was held at the King Edward Hotel at 1900 hrs on January 15, 1957. W/C J. G. Portlock, our Branch Chairman, presided and 60 members and guests were present. With W/C Portlock at the head table were Mr. G. L. Best and Mr. C. C. Young, Councillors; Mr. W. A. B. Saunders, Vice-Principal of the Calgary Institute of Technology and Art and Chairman of the C.A.I. Alberta Committee; Mr. H. C. Luttman, National Secretary of the C.A.I.; Mr. R. Whittaker, Secretary-Treasurer of Northwest Industries Ltd., who was representing the Sustaining Members; S/L J. A. G. Diack, Chairman of our Programmes Committee; and the Guest Speaker, Mr. J. H. Parkin, Director of the National Aeronautical Establishment.

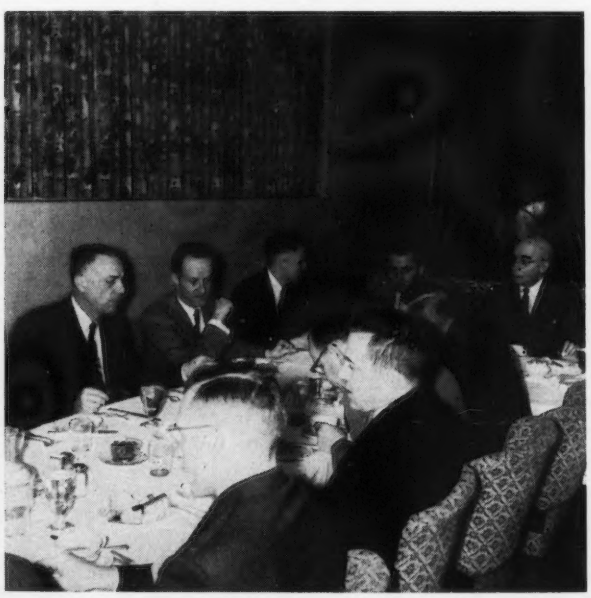
After an excellent dinner, the Chairman called upon Mr. Luttman to address the meeting. Mr. Luttman said that he was pleased with the progress that had been made during the past year and his kind words were most encouraging. He suggested that as many members as possible attend the forthcoming Mid-season Meeting at Winnipeg. The presence of Mr. Luttman added greatly to the success of this first Dinner Meeting.

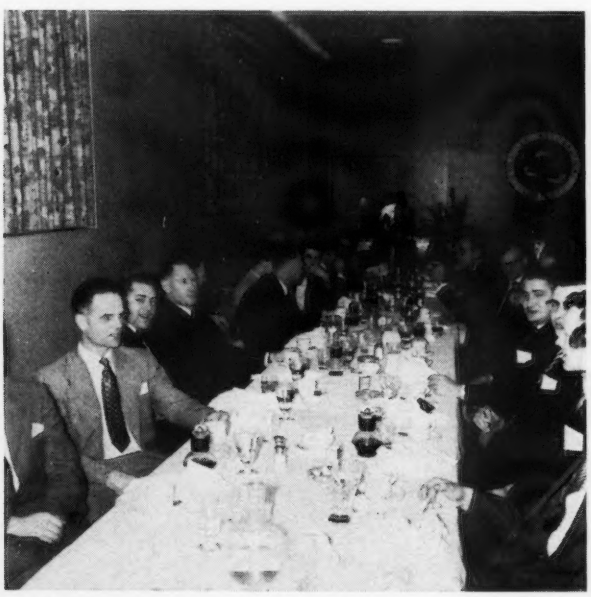
S/L Diack next introduced the guest speaker, Mr. J. H. Parkin, who had chosen as his subject "The Canadian Aeronautical Research Scene".

Mr. Parkin traced the history of Canadian aviation from its inception and showed that aeronautical research had begun at a very early date in Canada. The N.R.C., said Mr. Parkin, had carried out a great deal of fundamental research on many different problems and was set up to aid industry in the solution of technical problems that could not be handled by private industry organizations. It works closely with the aviation industry and Services.

At the conclusion of the talk, two excellent motion pictures were shown, one dealing with the development of the first Canadian jet engine afterburner and the other with helicopter icing tests.

At the end of this interesting programme, Mr. Parkin was ably thanked by Mr. Best.





Some scenes of the Edmonton Dinner Meeting

MID-SEASON MEETING

Programme

February 25 Afternoon 2.00 p.m.

MAINTENANCE AND OVERHAUL

Chairman
T. W. Siers
Assistant to the Director of Maintenance & Engineering
Canadian Pacific Air Lines Ltd.

Ground Servicing Equipment in Cold Weather Operations

S/L R. Sloat
Chief Project Engineer, CEPE Climatic Detachment, Namao

Servicing of Commercial Aircraft

R. J. Proctor
Manager Commercial Aircraft Servicing
Northwest Industries Ltd.

February 25 Evening 6.00 p.m.

RECEPTION AND DINNER

Chairman
T. E. Stephenson
President, Canadian Aeronautical Institute
Sales Engineering & Service Manager
Canadian Pratt & Whitney Aircraft Company Ltd.

Principal Speaker
S. H. Deeks
Executive Director
The Industrial Foundation on Education

Chinks in our First Line of Defence

February 26 Morning 9.00 a.m.

SAFETY AND SURVIVAL

Chairman
G/C J. R. Frizzle
Commanding Officer, RCAF Station, Namao

Survival Training in the R.C.A.F.

F/L R. J. Goodey
Officer i/c Arctic Detachment,
RCAF School of Survival Training, Cambridge Bay

The Saskatchewan Air Ambulance, Technical and Otherwise

D. N. Campbell
Supervisor and Chief Pilot
Saskatchewan Government Air Ambulance Service

February 26 Afternoon 2.30 p.m.

PLANT TOUR

Standard Aero Engine Limited
and
Bristol Aircraft (Western) Limited

MEETINGS

MID-SEASON MEETING

Notices giving the full programme of the Mid-season Meeting have been sent to all members of the Institute; the programme is also set out on the opposite page.

ABSTRACTS

The following are abstracts of some of the papers to be presented at the Mid-season Meeting.

Overhaul and Maintenance of Commercial Aircraft

R. J. Proctor–Northwest Industries

The servicing and maintenance of the smaller aircraft a few years back was carried out almost entirely out in the open due to the remote areas of the operation. Now that the larger and heavier type aircraft are becoming more prominent, the outdoor maintenance on these aircraft is not too satisfactory.

As certain inspections call for operational checks of systems that are impossible to do outside, Northwest Industries and other aircraft overhaul companies, who have been carrying out the overhaul of the heavier and larger aircraft, saw the need for commercial maintenance. Therefore, they acquired the necessary equipment and accommodations so that the aircraft could at all times be kept in an airworthy condition.

The outside maintenance is still being carried out to a large degree as it was in the past and unfortunately is showing signs of being unsatisfactory and very costly to the operators. Under these conditions it would appear beneficial to the commercial operator to have the servicing and maintenance of the larger aircraft carried out by an efficient servicing and maintenance company.

Survival Training in the RCAF

F/L R. J. Goodey–RCAF

(1) Purpose of survival training:

(a) To provide downed aircrew with sufficient knowledge to survive until rescued.

(b) To give aircrew greater confidence when flying over uninhabited regions and to reduce the likelihood of panic.

(c) To teach aircrew methods of assisting searchers.

(2) Survival school procedure:

Three major courses are given:

(a) Summer bush

(b) Winter bush

(c) Winter bush–Arctic

Five days of classroom training include lectures, films and demonstrations of:

(a) First aid

(b) Shelters

(c) Fire

(d) Signals

(e) Food and water

(f) Swimming

Ten days are spent at the bush camp area in the foothills of the Rockies. Civilian guides assist RCAF instructors in teaching the practical aspects of survival training.

On the Winter bush-Arctic course, students completing the foregoing training are flown to Cambridge Bay in the central Arctic for six additional days of training.

(3) Results of Survival training:

When a survival incident occurs, the school requests full data on the episode. All available information indicates that graduates of survival courses use their training to advantage.

The Saskatchewan Air Ambulance, Technical and Otherwise

D. N. Campbell–Air Ambulance Service

Introduction: eleven years of successful operation February 2, 1957 – only organized service of its type – authority for operation.

Purpose of the service: emergencies and how determined – categories of patient diagnosis and why carried – how flight requests originate and are recorded.

Personnel and equipment: pilots, nurses and engineers – aircraft type experimentation – experiences in proving various types – final standardization of aircraft and why.

Costs: in-province charges – out-of-province charges – cost to people of Saskatchewan.

Piloting: why the problem of restricted landing areas – system used for minimizing risks – problems of weather extremes – country night landings – other associated problems.

Nursing: required experience – complete responsibility for patient and what it means – nursing under severe space restrictions – medical equipment available.

Engineering: aircraft modifications, stretchers and other equipment – modifications for the provision of excessive stress on aircraft – particulars of modifications – other associated problems.

Safety record and conclusion: accidents and causes – improved availability of medical resources – cost and lives saved – problems still to be solved – psychological security.

MEMBERSHIP OF THE C.A.I.

as at 31st January, 1957.

Technical	**1720**
Associates	**72**
Total	**1792**

The Technical grades comprise the following:

Honorary Fellows	11
Fellows	24
Associate Fellows	198
Members	889
Technical Members	456
Technicians	39
Students	103

MEMBERS

NEWS

Dr. E. P. Warner, Hon. F.C.A.I., has been selected unanimously as recipient of the Wright Brothers Memorial Trophy for 1956. The trophy, given annually since 1948 for "significant public service of enduring value to aviation in the United States", is administered by the National Aeronautic Association.

I. A. Usher, A.F.C.A.I., formerly with Canadian Steel Improvement Ltd., has now taken up a position with Industrial Engineering Ltd., Vancouver, as Chief Metallurgist.

Dr. I. J. Billington, M.C.A.I., has recently left Canadian Westinghouse Ltd. to join Dilworth Ewbank Consulting Engineers.

H. D. Culham, M.C.A.I., has been elected as a representative of the Mechanical, Aeronautical and Industrial branch on the Council of the Ontario Association of Professional Engineers for 1957.

E. L. Greenwood, M.C.A.I., recently left the RCAF and is now employed on the technical sales and services staff of S. Smith and Sons (Canada) Ltd.

J. C. Vrana, Technical Member, formerly with the National Research Council, is now employed by the Canadian Pratt & Whitney Aircraft Co., Ltd.

DEATH

It is with deep regret that we announce the death of **J. R. C. Douglass, A.F.C.A.I.,** on the 3rd February, 1957. Mr. Douglass was 66. Having been engaged in aviation since 1919, he retired early in 1955, at which time he held the post of Supervisor of Inspection, Trans-Canada Air Lines.

ADMISSIONS

At a meeting of the Executive Committee of the Council, held on the 4th January, 1957, the following were admitted to the grades of membership shown.

Associate Fellow

C. H. Bottoms, Chief Engineer and Director, Lucas-Rotax Limited, P.O. Box 115, Stn. H, Toronto 13, Ont.

W/C A. N. le Cheminant, Chief Technical Services Officer, Box 22, RCAF Stn., Gimli, Man.

W. W. McKenzie, Section Chief, Mechanical Engineering Dept., Canadair Ltd., Montreal, P.Q.: *272 Labelle Blvd., Rosemere, P.Q.*

Member

R. G. Andrews, Chief Engineer, Aircraft Div., Aro Equipment of Canada Ltd., Box 515, Toronto 15, Ont.

W. E. Armstrong, Field Service Representative, Avro Aircraft Ltd., Malton, Ont.: *34 Roywood Terrace, Apt. 5, Ville le Moyne, P.Q.*

S/L M. R. Barrett, OC 10 TSU, RCAF Stn., Lincoln Park, Alta.

Sgt. J. C. Brooks, Airframe Supervisor, RCAF Stn., Cold Lake, Alta.: *c/o Sergeants' Mess, MPO 503, Grand Centre, Alta.*

W. M. Cairns, Section Chief, Materials and Process Engr. Lab., Canadair Ltd., Montreal, P.Q.: *1161 Gohier St., St. Laurent, P.Q.*

S/L W. G. Chandler (on transfer from Technical Member).

T. F. Cooper, Inspector of Aircraft, 10 TSU, RCAF Stn., Winnipeg, Man.: *231 Roseberry St., St. James, Man.*

P. R. Cope, Test Pilot, Avro Aircraft Ltd., Malton, Ont.: *73 Kingsway Crescent, Toronto 18, Ont.*

J. J. Eden (on transfer from Technical Member).

S. W. Farley, Sales Engineer, Canadian Pratt & Whitney Aircraft Co., Ltd., Montreal, P.Q.: *243 Fairfield, Greenfield Park, P.Q.*

I. S. Gauley (on transfer from Technical Member).

R. L. Gaudreau, Chief Test Pilot, Aircraft Industries of Canada Ltd., P.O. Box 100, St. Johns, P.Q.

CPO C. F. Gilhen, Air Engineer Officer, RCN Air Station, Shearwater, N.S.: *Box 83, Shearwater, N.S.*

CPO A. C. Green, Air Technician, RCN Air Station, Shearwater, N.S.: *Box 104, Shearwater, N.S.*

C. Gross (on transfer from Technical Member).

C. D. Handley, Section Head, Methods and Tool Engineering, De Havilland Aircraft of Canada Ltd., Downsview, Ont.: *93 Nipigon Ave., Willowdale, Ont.*

P. J. Harradine, Stress Engineer, Canadair Ltd., Montreal, P.Q.: *705 - 1st Ave., Bigras, Ste. Dorothee, P.Q.*

CDR (E) J. H. Johnson, Director of Air Engineering, RCN, Ottawa, Ont.: *761 Lonsdale Rd., Manor Park, Ottawa, Ont.*

L. A. Kendrick, Asst. Chief Inspector, Lucas-Rotax Ltd., Toronto, Ont.: *34 Bayard Ave., Scarborough, Ont.*

F. Kense, Overhaul Engineer, Rolls-Royce of Canada Ltd., Montreal, P.Q.: *5260 Randall Ave., Apt. 3, Montreal, P.Q.*

M. Kirste, Liaison Engineer, Canadair Ltd., Montreal, P.Q.: *2865 Goyer St., Apt. 15, Montreal, P.Q.*

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D. M. H. Lowe, Asst. Trials Coordinator, Canadair Ltd., Montreal, P.Q.: *9 - 18th Ave., St. Rose West, P.Q.*

W. H. Makin, Quality Control Analyst, Avro Aircraft Ltd., Malton, Ont.: *413 Mountain View Dr., Milton, Ont.*

Lt. (E) (A/E) (P) K. M. Meikle, Stn. Maintenance Test Pilot, RCN Air Station, Shearwater, N.S.: *20 Canterbury St., Dartmouth, N.S.*

G. A. Michaelov (on transfer from Associate).

F. N. Newell, Engineer. Canadair Ltd., Montreal, P.Q.: *149 Riverside, St. Eustache sur le lac, P.Q.*

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P. R. Payne, Aerodynamicist, Special Projects, Avro Aircraft Ltd., Malton, Ont.: *21 Norcross Rd., Downsview, Ont.*

Member (Cont)

Dr. J. F. Perrier, Missile Systems Engineer, Canadair Ltd., Montreal, P.Q.: *1963 Blvd. St. Germain, Ville St. Laurent, Montreal, P.Q.*

G. T. Perry, Manager, Vancouver Products Application Dept., Shell Oil Co. of Canada Ltd., Vancouver, B.C.: *378 Moyne Dr., West Vancouver, B.C.*

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Technical Member

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M. W. Hebert (on transfer from Technician).

G. F. Howard, Division Engineer, Aircraft Division, Thompson Products Ltd., St. Catharines, Ont.

J. F. Hutchinson, Inspector Aircraft Overhaul and Maint., Pacific Western Airlines Ltd., Vancouver, B.C.: *1045 Queens Ave., New Westminster, B.C.*

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Technician

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D. E. Waters, Draftsman, Canadair Ltd., Montreal, P.Q.: *4265 Plamondon Ave., Apt. 11, Montreal, P.Q.*

Student

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H. B. McCabe, Nova Scotia Technical College, Halifax, N.S.: *118 Vernon St., Halifax, N.S.*

H. Schlachta, Sir George Williams College, Montreal, P.Q.: *4920 Bessborough Ave., Montreal 29, P.Q.*

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C. F. Fincham, Special Asst. to VP Sales & Service, Canadair Ltd., 509 Commonwealth Bldg., 77 Metcalfe St., Ottawa, Ont.

W. R. Higgins, Sr. Routing Assistant, Trans-Canada Air Lines, Vancouver Airport, B.C.

W. H. Mackey, Aircraft Branch, Dept. of Defence Production, Ottawa, Ont.: *474 Mayfair Ave., Ottawa, Ont.*

G. Sellars, Eastern Division Aviation Manager, Shell Oil Co. of Canada Ltd., 660 St. Catherine St. W., Montreal, P.Q.

R. D. Turner, President, TransAir Ltd., P.O. Box 5, St. James, Man.

SUSTAINING MEMBERS

PSC Applied Research Ltd. and Field Aviation Co., Ltd., were referred to by Mr. D. N. Kendall, founder and operating head of the Canadian Hunting Group of Canada, in his optimistic forecast for 1957.

PSC Applied Research Ltd., Hunting's Canadian manufacturing unit in the instrumentation and electronic fields, starts the year with increasing demands for this type of service in Canada and with large commitments, particularly the large scale manufacture of R-Theta computers for the R.C.A.F. Its newly-opened environmental test laboratory, first commercial facility of its type in Canada, is getting increasing business.

The Group's aviation coast-to-coast supply business, carried out through Field Aviation Co., Ltd., at Oshawa Airport, has built up to about a million and a half dollars, a growth which Mr. Kendall expects to see continue in 1957. Other Field activities, such as inhibiting of R.C.A.F. aircraft, repair and overhaul of service and business aircraft, and the sales of such aircraft as the Provost Ab Initio Jet Trainer and Beech executive air transports, will continue.

Minneapolis-Honeywell Regulator Co., Ltd., has given some particulars of a new line of fast-acting, pneumatically operated industrial valves introduced by Honeywell's Valve Division.

The valve, known as Series 200, is available in two models, one a piston-operated throttling valve and the other a diaphragm-operated two-position valve. Both are especially designed to handle such gases as air, helium, nitrogen and argon, at pressures up to 10,000 psi. The valves allow pressure drops as high as 6,000 psi under flowing conditions. They work at temperatures from 40° below to 400°F. Even wider temperature variations are available in special versions.

Despite their small size (the throttling valve is 15 3/8" x 13 5/32"; the two-position valve, 10½" x 11⅝"), the two valves' stainless steel bodies make them suited for heavy duty. They have split-body construction with clamped-in seat ring.

Both valve types are also available in hand-operated models with the same body construction.

The Goodyear Tire & Rubber Co. of Canada Ltd. has released some interesting information about the rubber industry's first radiation laboratory recently opened at Akron.

The $125,000 laboratory is especially designed for exploration and development of rubber products that will perform satisfactorily in a radiation environment. Rubber is particularly sensitive to radiation. Excessive doses invariably damage rubber and often harden and embrittle it. Using radioactive Cobalt 60 from Atomic Energy of Canada, Ltd., Goodyear scientists will search for favourable compounding practices and for chemical additives to improve radiation resistance.

One of the more important projects being considered is development of radiation-resistant airplane tires for possible use on atom-powered aircraft of the future. Other goals of the irradiation program include seeking to initiate chemical reactions, such as polymerization and vulcanization of rubber and seeking to improve physical properties of plastics and resins.

Exposure to radiation of most types of raw rubber results in vulcanization. This opens up the possibility that vulcanization can be accomplished without adding sulphur or other chemicals or raising the temperature of the rubber.

Cobalt 60 was chosen as a radiation source for the new laboratory because of the wide variety of materials to be investigated. The radiation field can be made quite effective over large samples such as automobile, truck and airplane tires with Cobalt 60. It provides a flexibility which is especially desirable in a laboratory tool.

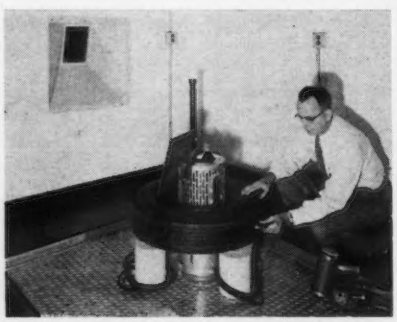
The Cobalt 60 is in the form of one-inch long cylinders, one-eighth of an inch in diameter and sheathed in a very thin sheet of aluminum. Nine of these cylinders are assembled in an aluminum "pencil" about 10 inches long. Goodyear's source consists of 72 of these pencils.

The Cobalt was activated in the NRX reactor at Chalk River, Ont., by Atomic Energy of Canada, Ltd. It was shipped by truck to Akron in a 4-ton lead container.

The modern air-conditioned laboratory is a ground floor structure, 42 x 42 ft. Inside is a heavily shielded area, known as the "cave", for housing the radioactive source. Next to it is a well-equipped physics and chemistry laboratory for the preparation of materials and test specimens and for the evaluation of results of radiation experiments.

The Cobalt 60 rests in the cave in a concrete and aluminum-lined well, 17 ft deep. Water in the well provides a shield for safe operation. An elevator in the well raises the radioactive source into an aluminum housing on top when experiments are being conducted and lowers it to the bottom again for storing. With the source under water, scientists can safely enter the cave at any time, to set up experiments or examine specimens (see cuts).

Samples to receive radiation can be placed in the centre of the housing for more intense radiation, or throughout the cave outside the housing. This arrangement removes practically all limits on the size and number of samples which can be subjected to radiation at the same time.



The Goodyear radiation laboratory

As industrial uses of atomic energy are put into effect, the demand will rise for rubber products such as hose, belting, gaskets and tires that will perform satisfactorily in a radiation atmosphere.

In chemical processing, radiation can serve as an alternative to heat and chemical agents for energizing or activating molecules and can increase the speed of many reactions. In some cases, radiation may even alter the course of a reaction favourably so that it yields completely new products.

One possibility is the formation of new types of synthetic rubber. Through radiation it may be possible to add monomers to a polymer already formed endowing the rubber with such desirable properties as resistance to certain types of solvents or low permeability to various gases.

How packaging films, such as Goodyear's Pliofilm, react to the pasteurization of food by radiation is another promising field of research. The effects of controlled doses of radiation on plastic materials, latex or rubber cements and adhesives offer many new avenues of new product development and improvement.

Canadair Ltd. and Orenda Engines Ltd. are to be congratulated on the recently announced order for 225 Sabre 6 aircraft (Orenda 14 engines) for West Germany.

Commenting on the order, Mr. W. R. McLachlan, President of Orenda, said that, along with current production of engines for Avro CF-100 and Canadair Sabres for the RCAF in Canada and Europe, it would be filled without expansion of Orenda's present production facilities. It was the third order from a foreign nation in less than a year involving Orenda engines – the previous two being sales of Canadair Sabres to the South African Air Force and the Republic of Colombia Air Force.

Mr. McLachlan said he and his associates felt that this latest order was a strong testimony to the long strides taken by Canadians in the brief period this country has been engaged in jet engine development. First jet engine research in Canada began in 1943 under the National Research Council. In 1944, a crown company, Turbo Research Ltd., was set up and began work on engine design. In 1946, when Turbo Research was disbanded, most of its personnel – about 85 men – joined the privately-owned A. V. Roe Canada Ltd. company at Malton. From that tiny nucleus, Orenda became a separate company in 1955 and now employs about 5,000. For the first Orendas produced, although the design was Canadian, about 95% of the parts were made outside Canada. As Canadian skills in jet engine manufacture have increased, now the situation is entirely reversed and about 95% of the engine is made at Orenda's main plant and in the plants of several hundred Canadian sub-contractors. More than 3,200 Orendas have been built for operational service since production began at the company's Malton plant in 1952.

Orenda also is attracting wide interest in the aviation world with a new Canadian jet engine, soon to be flight-tested. It is the Iroquois, designed for supersonic flight. For the early subsonic phases of flight testing, the Iroquois will be pod-mounted on the rear fuselage of a B-47 bomber loaned by the United States Air Force for that purpose.

Computing Devices of Canada Ltd. will now handle exclusively the airborne electronic communications and navigation equipment made by Bendix Aviation Corporation, formerly sold in Canada by Aviation Electric Limited.

This agreement is part of the comprehensive arrangements concluded during the summer between Bendix and CDC, whereby Bendix acquired a minority interest in CDC and CDC received exclusive rights to Canadian sale of a wide range of Bendix products.

The Communications equipment includes a variety of transmitter-receivers covering the HF, VHF and UHF bands. All meet ARINC specifications and have received widespread acceptance by military and civil users in Canada. Specific types are: the AN/ARC-45, an eight-channel lightweight UHF transmitter-receiver for small military aircraft and helicopters; the AN/ARC-44 FM transmitter-receiver communication system with 280 channels in the HF band; the TA-20A VHF transmitter with 360 channels; the corresponding receiver RA-18C; the MI-36A audio amplifier; the MI-51A cockpit loudspeaker system; the CNA-2C audio control panel; and the SCL-3 selective calling system.

Bendix equipment has filled a major part of the RCAF requirements of recent years for ILS facilities. The MN 85 (Localizer, VOR), MN 100 (Glide Slope) and MN 53 (Marker Beacon) receivers are used by commercial operators and, under the designation AN/ARN-14 and AN/ARN-18, have been adapted for military use.

As well as airborne equipment, the agreement covers the well-known Bendix mobile, railroad and portable transmitters and receivers.

Servicing of equipment covered in the agreement will be handled by CDC. With more than 200 engineers and electronics technicians on the staff, CDC is fully equipped to handle all servicing requirements on a fast efficient basis.

Computing Devices also announce the recent opening of their Computing Centre, equipped with a Reeves Electronic Analog Computer built to CDC specifications. CDC will rent out the use of the computer to other organizations who have need of the facilities which it can provide. As part of the service, CDC engineers are available to analyze a customer's problems, formulate the differential equations and set up the computer to solve the equations. Alternatively, there may be cases where the problem is of a confidential nature and the customer may not want to explain it in the detail needed by the operator of the computer. In such a case, the CDC analog computer team will instruct the customer's engineers in the necessary techniques and leave them to work on the computer alone.

The aircraft industry has used analog computers extensively since they were first developed in a practical form just after the war. The complexities of aerodynamic calculations are greatly speeded by the use of an analog computer. Structural problems, airframe design, engine performance, navigation systems, stability and general aircraft performance are all studies that lend themselves naturally to analog analysis.

BOOKS

The Principles of the Control and Stability of Aircraft. By W. J. DUNCAN. Cambridge University Press, 1956; Canada, The Macmillan Company of Canada Ltd. 384 pages. Illus. $8.50.

This book is one of the few good texts on aircraft stability and control, a subject which is becoming more important and more complex as time goes on. The reasons for this are that the effects of the compressibility of the air at high flight speeds, the distortion of the aircraft structure and so on, can no longer be neglected in many practical cases.

Professor Duncan's book is actually the first of the new Cambridge Aeronautical Series. Its treatment of the subject is reasonably up-to-date and comprehensive and avoids the use of difficult mathematics, and it certainly should help to fill a real gap in the literature.

The influence of the compressibility of the air and of structural distortions are treated in separate chapters. There is also a good chapter contributed by Professor A. D. Young on stalling and the spin. In all cases the treatment is fundamental in nature, clear and easy to follow.

Some phases of the subject are not treated, or are only briefly mentioned, but many of these could hardly be discussed fully in a single text. Sophisticated mathematical methods of solution and the use of automatic computer techniques are not discussed, nor is the general subject of flutter.

Automatic pilots and methods of automatic stabilizations of aircraft are described briefly.

The symbolic notation used in the text conforms with British usage, but a table of symbols is given in which the equivalent American terms are listed.

There is little doubt that the book would be a useful text for university students and would be also a valuable addition to the library of the practising aerodynamicist.

R. J. TEMPLIN

Wing Theory. By A. ROBINSON AND J. A. LAURMANN. The Macmillan Company of Canada Ltd. — Cambridge Aeronautical Series, 1956. 569 pages. Illus. $12.75.

The theory of wings and airfoil sections is one of the key subjects which underlie the practice of aeronautical engineering. There has not existed heretofore a comprehensive exposition of this subject in a single volume and the authors have done an important service in producing the present book.

The material is organized into five chapters which deal with (1) Foundations, (2) Two-dimensional airfoils, (3) Finite wings, (4) Compressible flow, subsonic and supersonic, and (5) Unsteady motion. The book is self-contained in that it includes the material from hydrodynamics and gas dynamics which is needed for application to wing theory. Reviewer feels that the book might have been improved by more subdivision of the material.

The main emphasis is on the mathematical aspects of the theory, although the authors have included helpful discussions of the physical nature of the flows involved and have taken cognizance of the engineering problems to which the theories are applied. The book is clearly written and has achieved a high level of scholarship. The mathematics is clearly presented and rigorous (at least insofar as the reviewer, an engineer, is qualified to judge). Although all the essential steps are included, nevertheless many engineers will find the mathematics difficult. This is partly because the subject is inherently difficult and partly because of the sophisticated presentation.

In the reviewer's opinion, this definitive work will be valuable for many years to come as a reference text for engineers and applied mathematicians engaged in research and development and for graduate students.

B. ETKIN

Radio Telemetry. By M. H. NICHOLS AND L. L. RAUCH. John Wiley and Sons, 1956. 461 pages. Illus. $12.00.

For the practising engineer, the equipment designer or the serious student of telemetry, this book meets a long felt need. It provides a basic text on the subject, comprehensive in scope, yet very readable and well balanced in the treatment of theory and technique.

It is seldom possible to place a book on the market dealing with a rapidly evolving subject such as radio telemetry and at the same time avoid a large measure of obsolescence in the material presented.

The authors have done just that. They have outlined the problems involved, developed the basic theory, summarized the requirement and described a wide range of successful equipment in current use. The excellent treatment of the data reduction and information presentation aspect of the subject deserves special mention. Too little attention has been devoted to this vital problem in the past.

J. S. PARSONS

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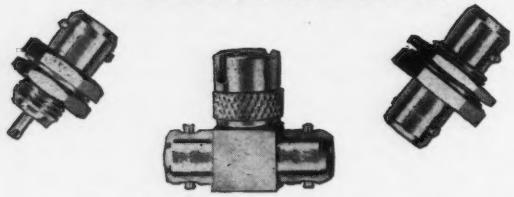

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Technician	Engaged in technical work in aviation	$5.00 ($2.00)
Technical Member	Engaged in science, engineering, research, manufacture or operation, in aeronautics or related fields, for 4 years or graduated from an approved school of engineering or science	$7.00 ($4.00)
Member	Engaged in aviation for 8 years and acquired a recognized standing	$8.00 ($4.00)
Associate	Engaged in aviation, though not qualified for technical grades	$8.00 ($4.00)
Associate Fellow	Engaged in aeronautical science or engineering for 10 years and been in responsible charge or made outstanding contribution	$9.00 ($5.00)
Fellow	Been an Associate Fellow for 1 year and attained distinction in aeronautics	$10.00 ($5.00)

MEMBERSHIP REQUIREMENTS

Individual membership of the Institute is divided into seven grades requiring qualifications which are defined in Article 7 of the By-laws. These qualifications are summarized in the table above.

APPLICATIONS

Application for membership must be made on the approved form, which can be obtained from the Secretary, and which must be returned to the Secretary on completion. The applicant does not apply for membership in any specific grade, but each application is carefully considered by an Admissions Committee, who submit their recommendations in this regard to the Council. The Council is the deciding body. On admission the applicant is informed of his grading and the appropriate entrance fee and dues.

ENTRANCE FEES

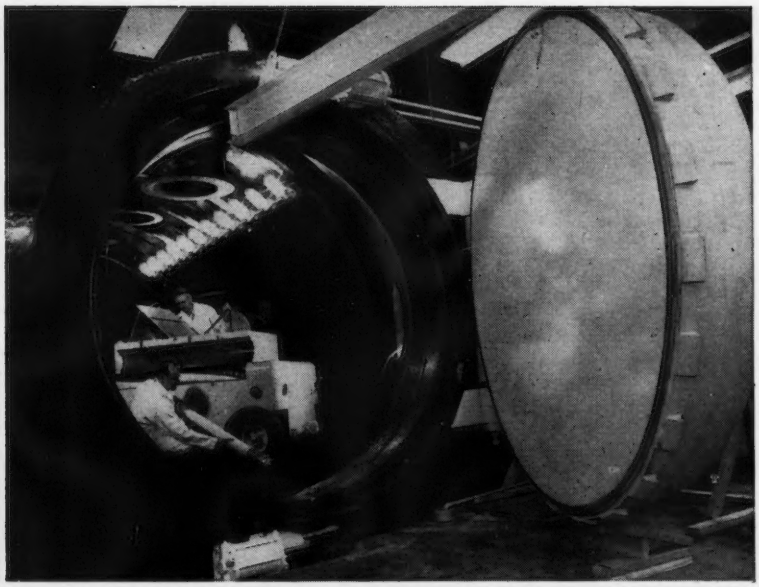
The Entrance Fee is $5.00. Members in good standing in the R.Ae.S., I.A.S., I.A.T. or O.A.S., on the 1st of January 1954, who were resident in Canada at that time, are admitted without payment of entrance fee. Students and Technicians are also exempt from entrance fee but must pay a transfer fee, which is in effect a deferred entrance fee, when they transfer later on to one of the senior grades.

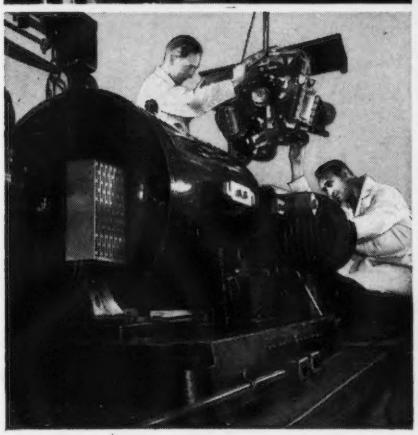
SPECIAL ANNUAL DUES

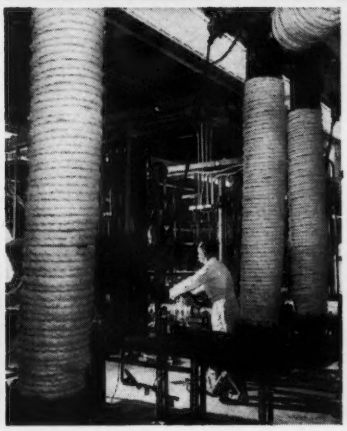
Members, who are also members of the R.Ae.S., I.A.S. or E.I.C., or who are resident outside Canada or the U.S.A., enjoy a reduced rate of annual dues. This reduced rate is shown in brackets in the right-hand column of the above table.

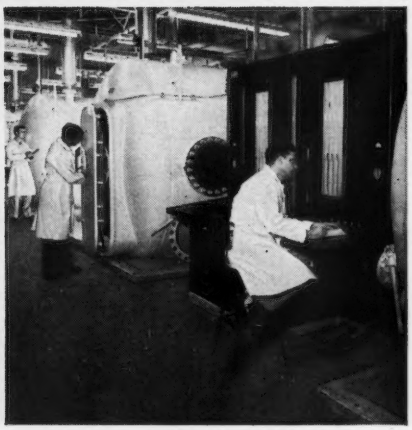
SUBSCRIPTION TO C.A.I. PUBLICATIONS

Annual dues include a non-deductible subscription to the Canadian Aeronautical Journal.









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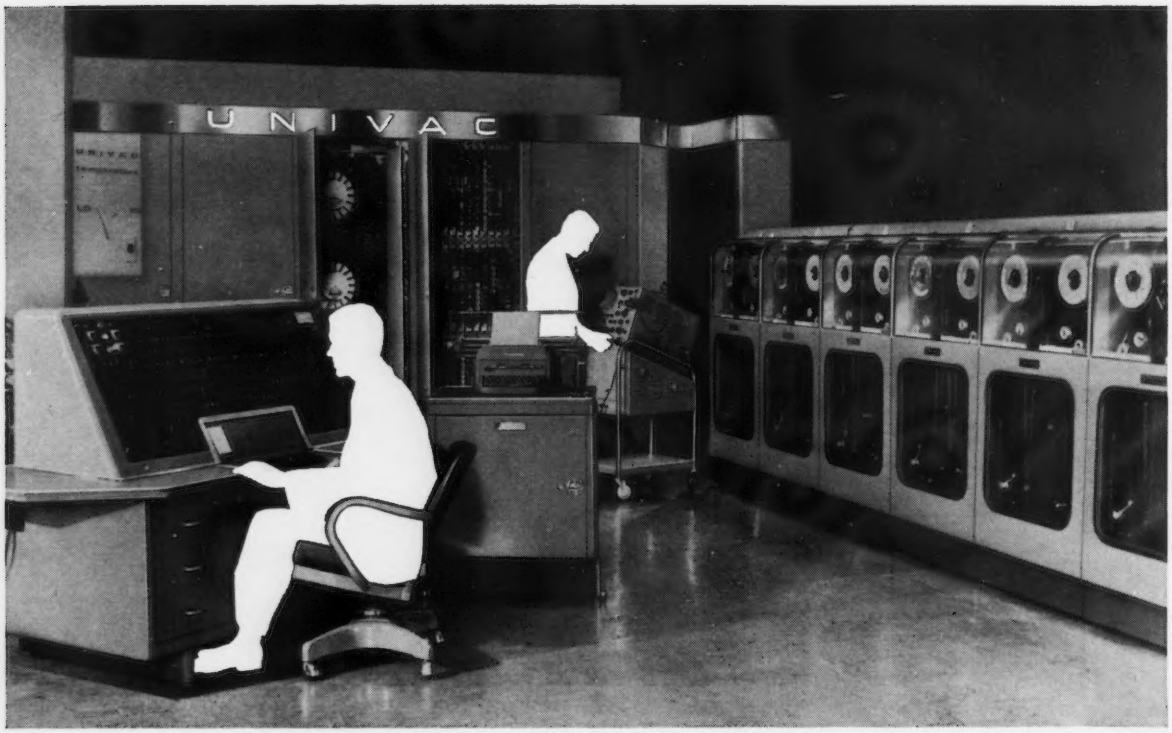

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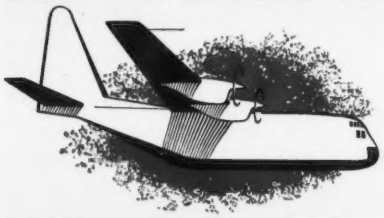
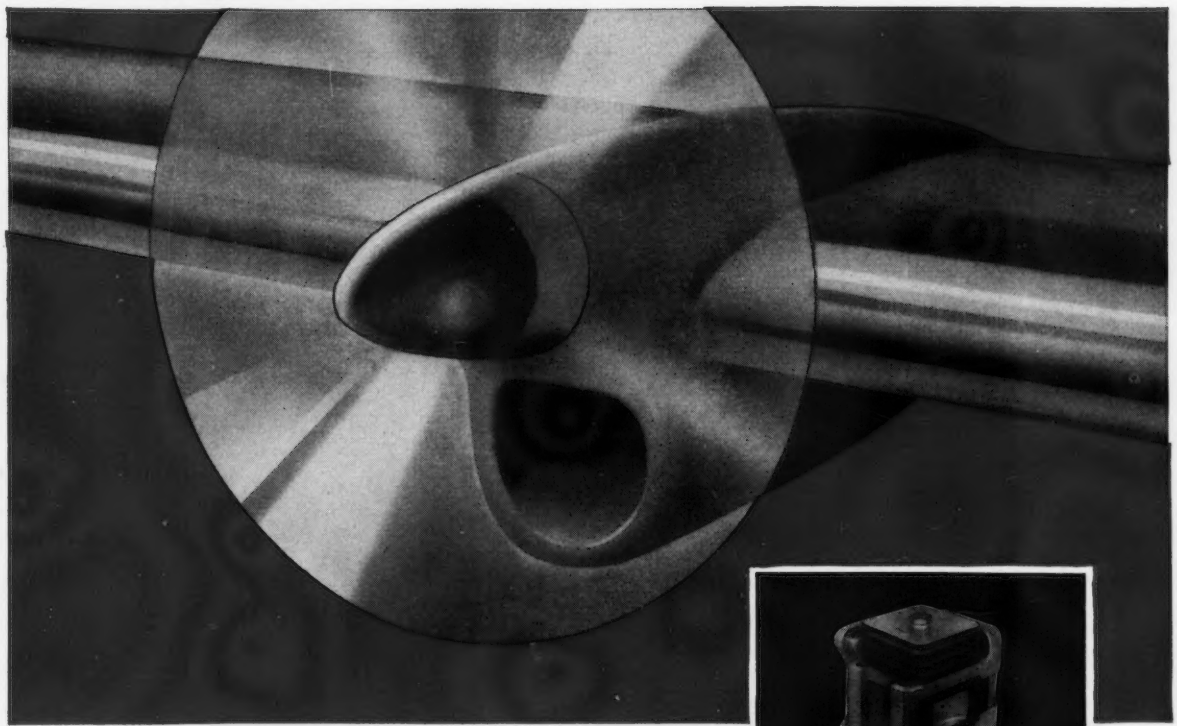
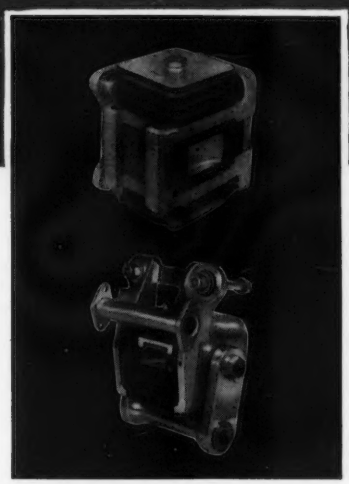


the case of the "hot turbo-prop"





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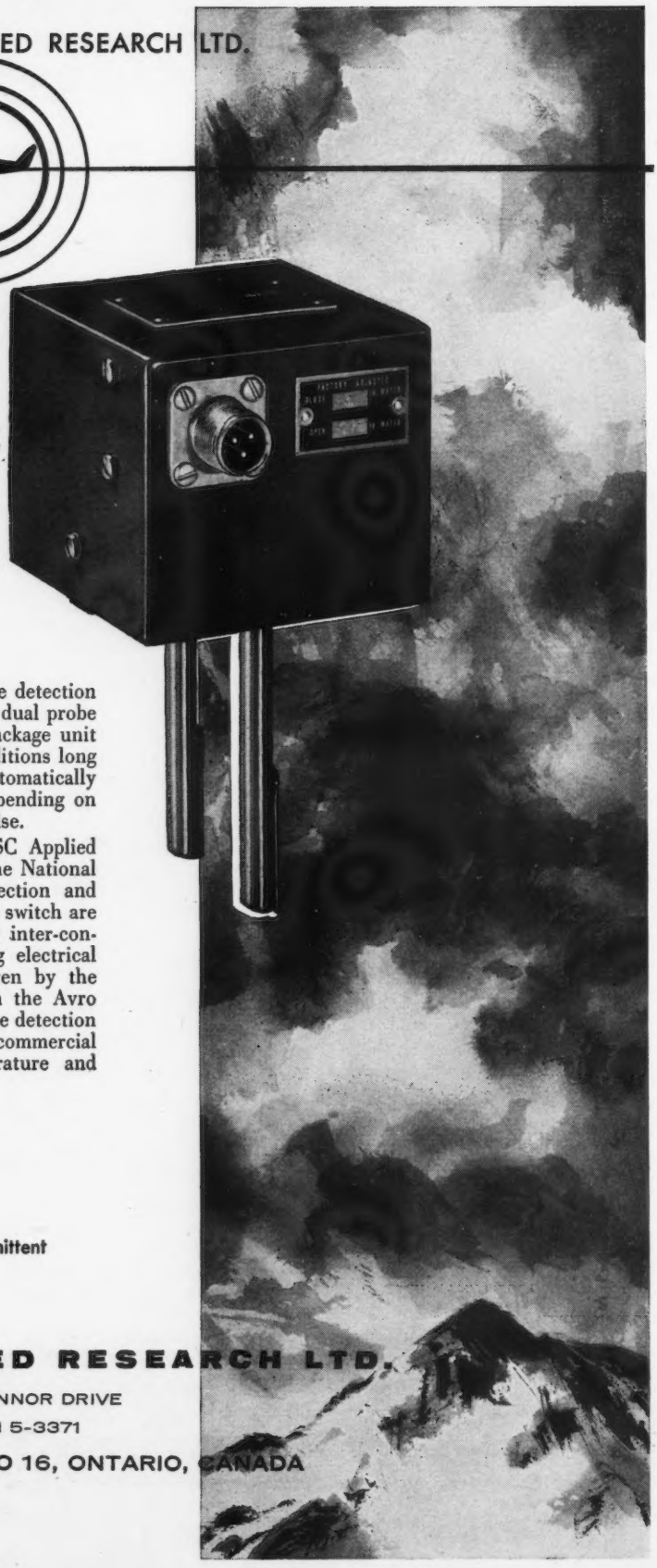

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